Office of the Organising Secretary, IMHC
P O Box 2963, FOURWAYS 2055, Rep. of South Africa
Telephone and Fax:+27 (0) 11 888-7163
web site : http://www.cmasa.co.za
e-mail : cma@pixie.co.za

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Intelligent Conveyor Drives for Underground Conveyors

Mr. Louis Botha
Brandspruit Colliery , Sasol Coal, RSA

The SA Institution of Mechanical Engineering

SA Institute of Materials Handling

INTELLIGENT CONVEYOR DRIVES FOR UNDERGROUND CONVEYORS

Mr Louis Botha
BRANDSPRUIT COLLIERY – A division of Sasol Coal

1. INTRODUCTION

This paper has been prepared to share with the mining industry the experience gained by Brandspruit Colliery on intelligent conveyors. Intelligent conveyors at Sasol Coal was initiated at Brandspruit Colliery and implemented in 1996.

Brandspruit Colliery is part of the Sasol Coal complex at Secunda, which consists of six underground mines and one strip mine. These mines deliver 46 million tons of coal per annum to the two synthetic fuel plants at Secunda and 3 million tons of coal to the export market.

Brandspruit Colliery produces in average 8,7m tons of coal per annum with a peak of 9,1 million tons in 1997/1998. The coal is produced from 10 continuous miner sections over an area of approximately 2600-hectare underground.

The total length of underground trunk conveyors at Brandspruit is approximately 30km, and that of the underground section conveyors approximately 28km. These conveyors transport the coal from the working face to a surface bunker.

This paper is a follow up of the paper presented by Mr. Philip Venter at Beltcon 8. In that paper possible solutions were discussed to address the problems related with the increase in production that faced Brandspruit.

In this paper intelligent variable speed conveyors as well as case studies of two typical installations will be discussed.

2. PROBLEM ANALYSIS

2.1 Conveyor specifications prior to 1996

2.1.1 General

The mine used two widths of conveyors underground, 1200-mm and 1500-mm wide. With the exception of two trunk conveyors, which were 1200-mm wide, all other trunk conveyors were 1500-mm wide. All section conveyors, feeding trunk conveyors, are 1200-mm wide.

In all cases 3 roll 35° troughing idlers were used.

2.1.2 Speed

The conveyors ran at two different speeds. High capacity conveyors at a speed of 3,7m/s and limited load conveyors, (i.e. 3 sections) at 2,7m/s. These were fixed speed conveyors.

2.1.3 Conveyor belt Specification

Belting were all solid woven PVC, Class 1250. The average belt life on underground conveyors when compared to surface conveyors, which are running at a fraction of the cost, is a matter of great concern to the mine. In the quest to reduce life cycle costs of conveyor systems, different types of belting are currently being tested and specifications reviewed.

In order to increase belt cycle times and hence reduce life cycle costs, conveyor lengths have been increased to a current maximum of 3300m.

2.1.4 Power Packs

Only two types of motor sizes were employed, 90kW and 200kW, using 1000V AC supply (multiple applications). These are deployed in various configurations, between one and four per conveyor drive depending on power requirements. Two gearbox ratios were employed, resulting in conveyor speeds of 3,7m/s and 2, 7m/s respectively. Fluid couplings were of the double delay chamber type (TVV). Power packs are of modular design, flange mounted and torque arm supported to eliminate alignment problems.

2.1.5 Take-ups

All installations were fitted with 2-speed electric winch take-ups, which give satisfactory but not optimal control during starting and stopping of conveyors.

2.1.6 Conveyor system control

All conveyors were centrally controlled on the surface through a telemetry system. The information regarding all conveyance parameters is available on a computer network on surface. Persons on surface interested in, for example tonnage produced from an area for the shift at any moment in time may enter the window for the conveyance system and immediately have the information displayed on the screen. In addition the system shows which belts are running and/or standing, bunker levels, motor currents and tons per hour.

2.2 Production

2.2.1 Background

Most production facilities in a growing environment are faced with unique problems. Brandspruit Colliery, referred to in this paper, is no exception. Normally, the engineer is faced with certain fixed limitations when production increases, resulting in growth in performance demand from existing facilities.

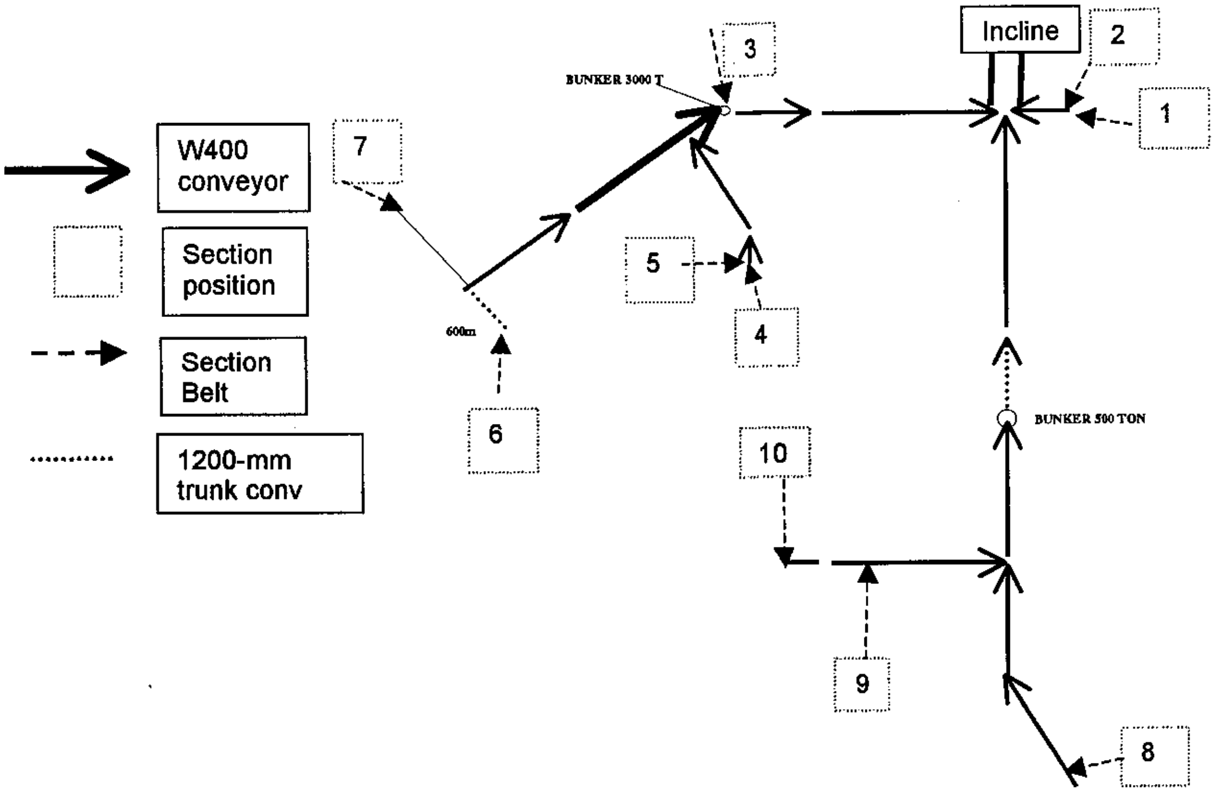


FIGURE 1 - Conveyor layout in 1995

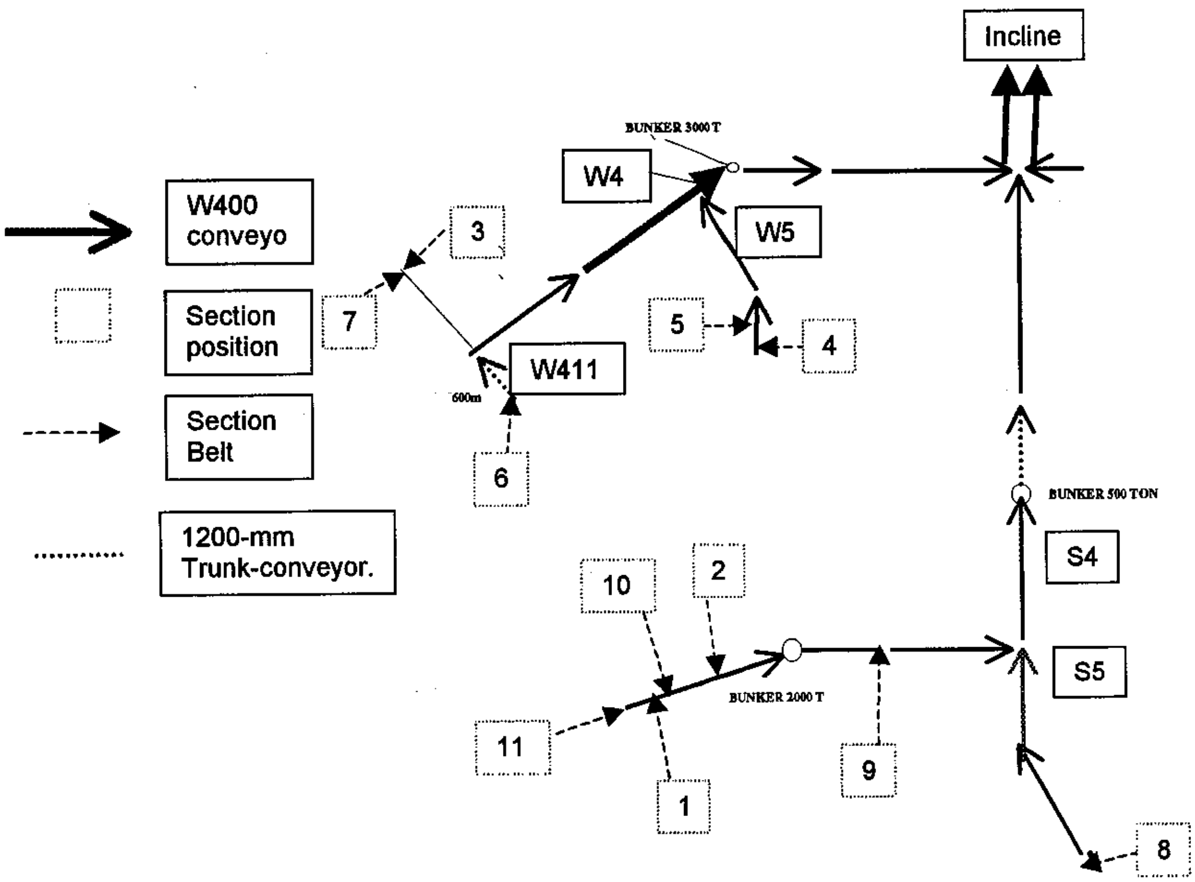


FIGURE 2 - Conveyor layout in 1997

Figure 1 shows the placement of production sections in the mine during 1995 when 7.5 million Tons per annum was produced.

Figure 2 shows the placement of production sections in the mine in 1997 when 9,1 million tons per annum had to be produced.

2.2.2 Problem Discussion

The production of the mine historically came from three directions to an intersection at the twin conveyor inclined shaft bottom. Average production amounted to 7,5 million tons per annum. Two events have to be dealt with simultaneously:

I. one of the three production areas was nearing the end of it's life, requiring the balance of production to be added to the remaining two production areas and

II. total production was to increase to 9,1 million tons per annum, the additional 1.4 million tons were to be allocated to the same two remaining production areas. Specific mine layouts and existing main conveyor installations as well as underground bunker positions further compound the problem. This was mainly due to fixed capacities of the existing operational system.

If FIGURE 1 and FIGURE 2 are compared, it is clear that on FIGURE 1, the conveyor systems are fairly well balanced in respect of sharing conveyance requirements. In no instance were more than four sections feeding on any one trunk-conveyor. In FIGURE 2, it becomes clear that congestion will take place on the West 4 conveyor, where up to 5 sections were required to feed on.

A simulation was done to determine what load capacities would be required to accommodate the higher production tempos. Table 1 is a summary of this simulation. From this information it was clear that for less than 2% of the time the belt needs to run faster that 3,7m/s and for 98% of the time the belt can run slower than 3,7m/s. This is where the biggest opportunity for variable speed drives was identified.

Capacity (t/h)	Conveyor Speed (m/s)	% of the Time
0	1.5	21.60%
1100	1.5	38.73%
2200	1.96	27.79%
3300	2.94	9.97%
4400	3.92	1.79%
5500	4.9	0.13%

TABLE 1 - Simulation of production peaks

3. POTENTIAL SOLUTIONS

3.1 General

By the evaluation of all current and new conveyor-drive options the following possible solutions were considered:

- Governing section output by reducing feeder rates.
- Double conveyor system.
- Wider conveyors.
- Faster/constant speed conveyors.
- Variable speed conveyors.

Various options under variable speed conditions were investigated. They were:

- DC variable speed systems.
- Hydraulic systems.
- Switched reluctance motors.
- AC variable speed system.

The final decision was between AC or DC variable speed drives.

In early years DC motors were used as variable speed drives, because they could easily achieve the required speed and torque. However, the evolution of AC variable speed drive technology has been driven partly due to the desire to emulate the excellent performance of the DC motor, such as fast torque response and speed accuracy, while using rugged, inexpensive and maintenance free AC motors.

After careful consideration of the various options in a final analysis, the decision was taken to install AC variable speed drives, utilizing Direct Torque Control technology.

3.2 Why AC Variable Speed Drives?

A number of criteria were taken into consideration for this decision, a few of the most important areas are as follows:

- Technology.
- Product support/service.
- Delivery.
- Economy.
- Compatibility.
- Keep it simple.

The final decision was made to purchase the Asea Brown Boveri (ABB) Direct Torque Control variable speed drives as described hereunder.

3.3 Direct Torque Control Technology

3.3.1 Background

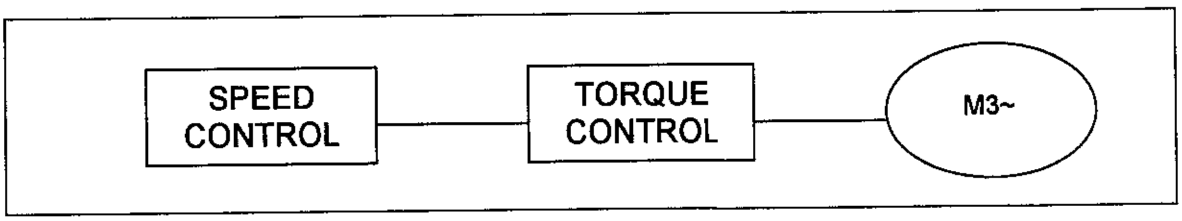


FIGURE 3 - Open Loop Control of an AC drive using direct torque control

With the direct torque control technology, field orientation is achieved without feedback, using advanced motor theory to calculate the motor torque directly and without using modulation. The controlling variables are motor **magnetizing flux** and **motor torque.** There is no modulator and no requirement for a tachometer or position encoder to feed back the speed or position of the motor shaft (open loop control). It uses digital signal processing hardware and an advanced mathematical model of how a motor works. Ref to FIGURE 3.

The result is a drive with a torque response that is typically 10 times faster than any AC or DC drive. The dynamic speed accuracy of DTC drives will be 8 times better than any open loop AC drives and comparable to a DC drive that uses feedback. DTC produces the first "universal" drive with the capability to perform as either an AC or DC drive.

3.3.2 Why is it called Direct Torque Control (DTC)?

Direct Torque Control describes the way in which the control of torque and speed are directly based on the electromagnetic state of the motor, similar to a DC motor, but contrary to the way in which traditional Pulse Width Modulation (PWM) drives use input frequency and voltage. DTC is the first technology to control the "real" motor control variables of torque and flux.

3.3.3 What is the advantage of DTC?

Because torque and flux are motor parameters that are being directly controlled, there is no need for a modulator, as used in PWM drives, to control the frequency and voltage. This, in effect, cuts out the middleman and dramatically speeds up the response of the drive to change to the required torque. DTC also provides precise torque control without the need of a feedback device.

4. INTELLIGENT CONVEYORS

4.1 Case study 1 - Brandspruit West 4 Conveyor

4.1.1 Background

In view of the identified problems (refer paragraph 2.2.2 – Problem Discussion), Conveyor W400 was identified as the bottleneck in the system as indicated in FIGURE 4. FIGURE 4 shows the present layout of all the trunk conveyors at Brandspruit, as well as planned expansions.

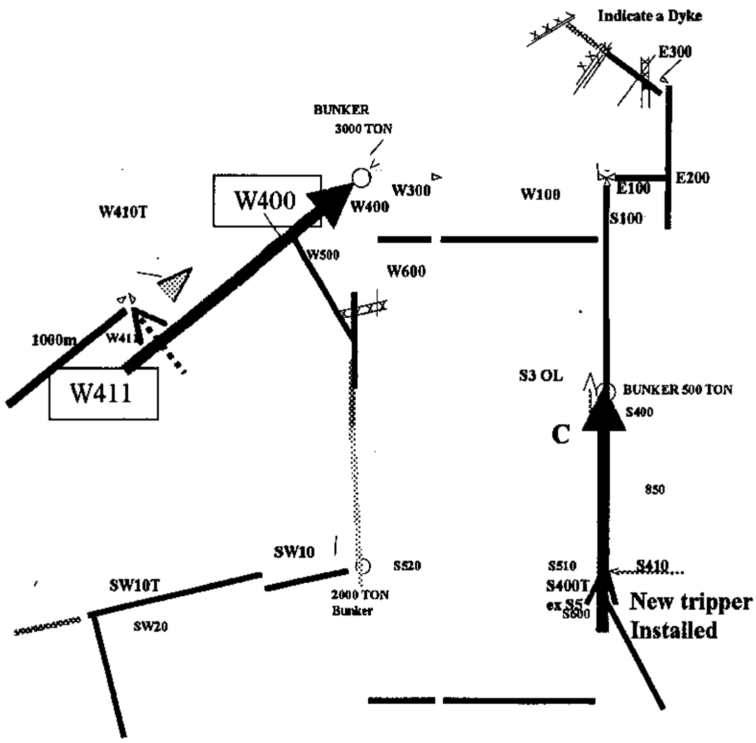


FIGURE 4 - Present Trunk Conveyor Layout

The first variable speed drive was installed in 1996 at W411 as indicated in FIGURE 4. This installation served only one section and therefore the technology and principle could be tested with limited risks. After one year in operation without a breakdown, it was decided to install the intelligent conveyor W 400.

Although the initial intention was to accommodate higher production peaks, this became a secondary issue as the opportunities of cost savings became clearer.

4.1.2 Conveyor layout and general specification

The following graph FIGURE 5 and TABLE 2 shows the elevation of and the technical specifications of the conveyor.

WEST 4

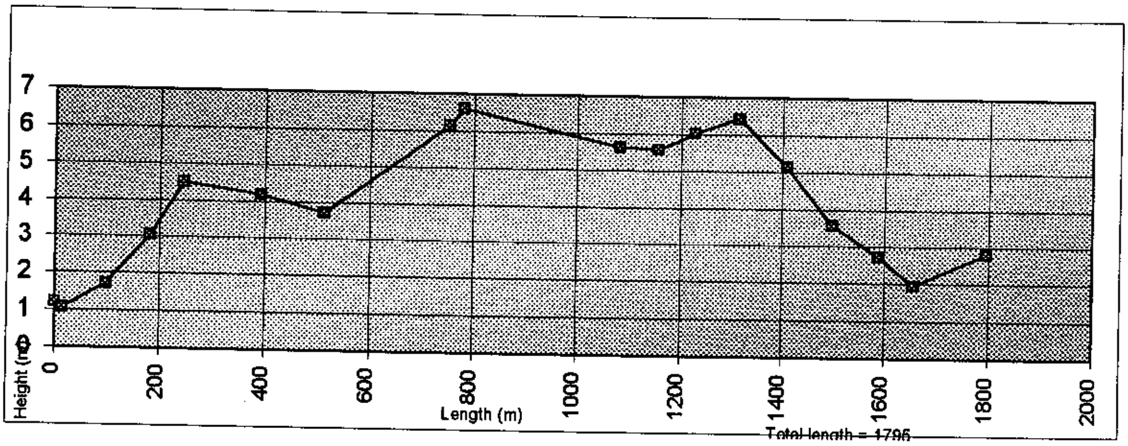


FIGURE 5 - Drive layout

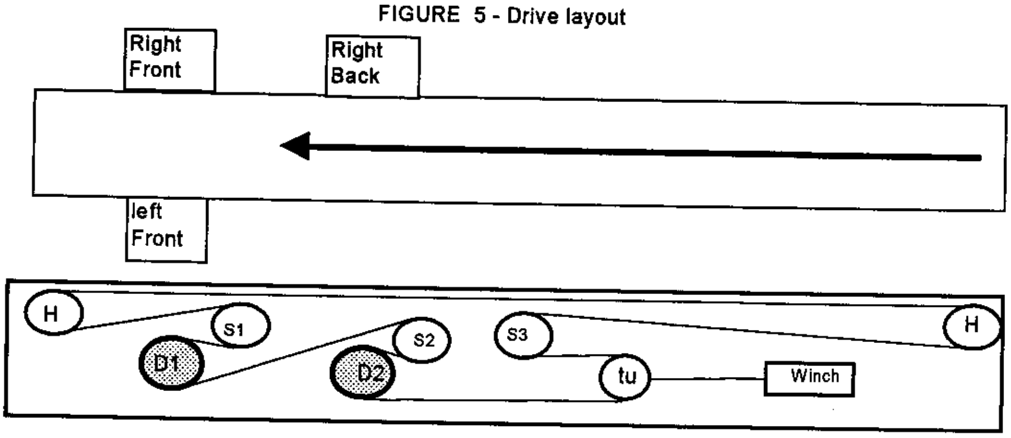


FIGURE 6 - Conveyor specifications

		Right front	Left front	Right back
gearbox	Make	Hansen	Hansen	Hansen
	Ratio	20:1	20:1	20:1
Motor	Make	WEG	WEG	WEG
	kW	260	260	260
	Voltage	380	380	380
Drive -VSD	Make	ABB	ABB	ABB

Idler spacing (Trough)=	1.8 m	Belt Length=	1795.2 m
Idler spacing (Return)=	3.6 m	Belt width=	1500 mm
Idler diameter =	152 mm	Lift =	1.610
Shaft diameter =	30 mm		

Drive system efficiency= 92.8%

TABLE 2

FIGURE 7 indicates the principle of the control of the Powerpack by the VSD system

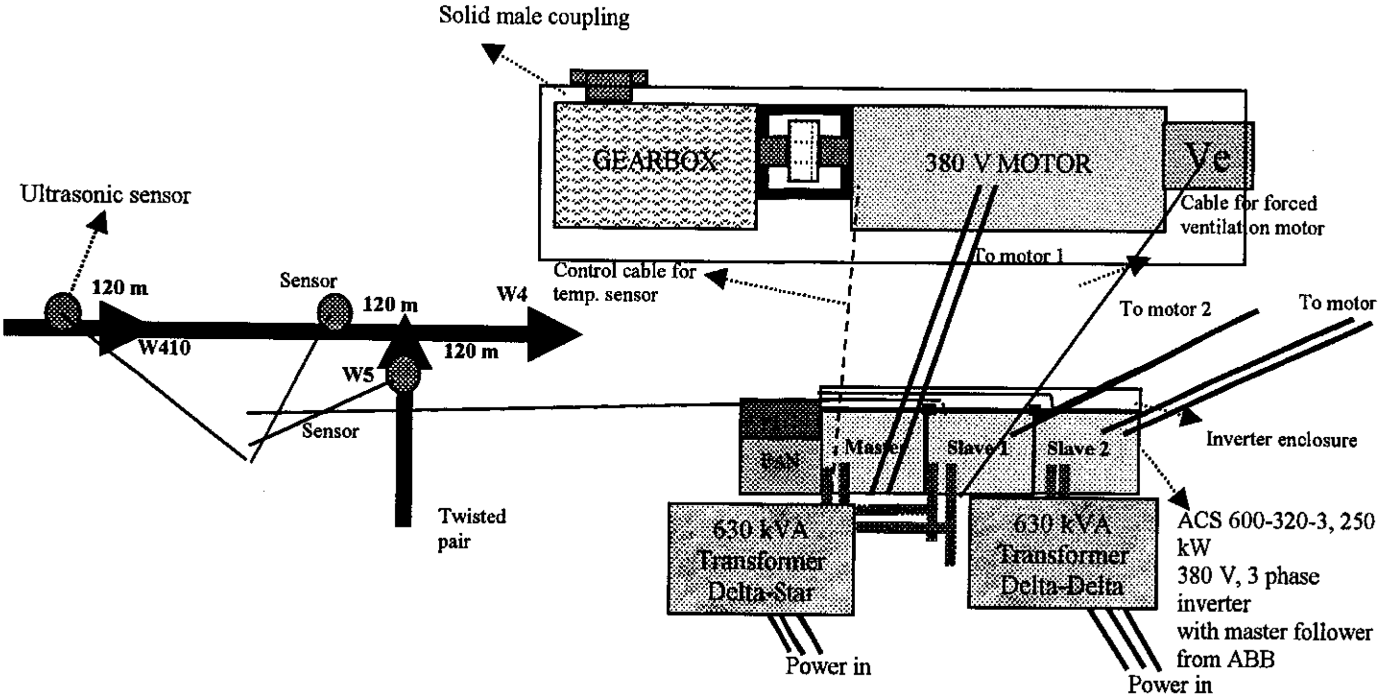


FIGURE 7 - System Layout

4.1.3 Belt Speed and Operation

There are three ultrasonic level detectors installed on the conveyor belts to measure the level of coal on the different belts. Each sensor is installed 120m from the transfer points. This distance is necessary to compensate for the ramp-up time of the VSD. Because coal will be loaded on Conveyor W4 from conveyor W5 and W410, care need to be taken on the variances of the coal loaded on W4. It is important that enough distance is available between the sensors and discharge points, so that the coal discharged from W5 and W410, will not result in the overloading of Conveyor W4.

The three (3) sensors send a 4 to 20mA signal to the PLC at W4. According to these signals the PLC does the necessary calculations and determine if the sensor on conveyor W410, conveyor W5 or the sensor on conveyor W400 or the combination will be used as reference. From this calculation the speed of W4 is determined and controlled through the master VSD.

With the initial start up the belt ramps up to 500rpm. If any one of W410 or W5 is started the belt will ramp up to 1600rpm. Only after 3 minutes will it start to control the speed according to the sensor level signals. It will now control the speed between seven preset speeds of which the lowest is 500rpm and the highest 1600rpm. The sensor must sense less coal for 20 seconds continuously before the belt will reduce speed. If the sensor senses more coal for 2 seconds the belt will speed up. The distance of 120 m from the sensing point to the discharge point of the two conveyors is sufficient for the conveyor to speed-up to the required speed.

4.1.4 Conveyor tension

A comparison between the start-up tension of W4 fitted with a TVV fluid drive coupling, and the start of W4 with a VSD drive, can be seen in FIGURE 8 (See Appendix A)

Present set starting time is 180 seconds. This time can be set to as long as 1000 seconds. Different ramping profiles can be used during starting, dependent on the user's requirements. Starting dynamic influences in the design can therefore be minimized as far as possible.

Dynamics during emergency stopping are still a factor, due to legal requirements – "all power to be removed in the event of an emergency stop". During normal stopping, a stopping ramp can be introduced, resulting in a smooth stopping tension.

4.1.5 Analysis of the voltage and harmonics measurements

Measurements were conducted (with a 2 minute averaging period) of the fundamental (50Hz) and harmonic voltages and currents at each underground PFC installation 11kV supply, in order to ensure that existing system supply conditions are acceptable. This was done to determine the effect of the VSD drives on the power quality and to determine if harmonic filtering was required or not.

Results of the 50Hz and harmonica voltages measured at the 11kV supply are shown in attached FIGURES 9 and 10 (Appendix A).

Based on the results of the above voltage measurements, the long term average and maximum 2 minute 50Hz voltage, voltage total harmonic distortion (THD) and significant individual harmonic voltages recorded are listed in the following table (TABLE 3):

	VOLTAGE % OF NORMAL 11KV	
	Long term average	2-min average
50Hz	103,6	105,4
THD	1,04	2,49
5	0,64	2,06
7	0,59	2,47
11	0,25	1,26
13	0,17	0,63

TABLE 3

At the supply, the peak harmonic voltage magnitudes above the 13th harmonic were <0,5% of nominal voltage.

The voltage distortion compatibility level for each odd harmonic up to the 25th harmonic as listed in NRS-048 (Draft 7-1997) for 10-minute average values at an 11KV (i.e. MV) supply are listed below :

	Compatibility level (% of nominal voltage)
THD	8
HARMONIC no	
3	5
5	6
7	5
11	3,5
13	3
17	2
19	1,5
23	1,5
25	1,5

TABLE 4

The 50Hz and harmonic conditions recorded were well within accepted "quality of supply" limits (i.e. specified in NRS-048) and therefore acceptable.

From the measurement results it can be seen that the largest individual harmonic voltage present on the 11KV supply was the 7th harmonic with peak magnitudes of 2,47% of nominal voltage, and was responsible for a significant position of the total voltage distortion present. This 7th harmonic mainly results from amplification of the 7th harmonic currents generated by the connected underground loads (e.g. mining machines), due to parallel effects between the PFC capacitance and supply inductance.

However the NRS-048 defined limit for 7th harmonic voltage at an 11kV system is 5% of nominal fundamental voltage, and the existing 7th harmonic voltage supply are therefore acceptable.

4.1.6 Power savings

To ensure that the system is economical viable, monthly operating cost for a fluid coupling (Fixed speed) system as well as the operating cost for a variable speed system were determined.

Absorbed power required is first calculated, taking into account the change in effective tensions and speed differences.

From these calculations the system power is calculated using the following formulas:

System Power (Fluid coupling) = Absorbed power / (ηm x ηT x ηF x ηg)

System Power (Variable speed drive) = (Absorbed power) / (ηm x ηT x ηD x ηg)

Efficiency (η) description as follows:
m – motor; T – Transformer; D – variable speed drive; f – fluid coupling; g – gearbox

From the calculations performed, the system power cost for a Fixed speed system (fluid coupling) is R19 493.39 / month, and that of a variable speed drive system is R16016.12/ month.

This results in a saving of approximately R3 477.00 / month

4.1.7 Capital outlay

Calculations were carried out in **1995** to determine the difference in cost, for the alternative options to upgrade the conveyor belt system. This was done to accommodate the expected higher production peaks.

To upgrade the drive system for a fixed speed system, to handle the expected production, would have cost approximately R 770 726 (January 1999) (Only certain items needed to be replaced).

However to install a total new drive system (VSD), would have cost in the region of

R 1 113 456 (January 1999).

In FIGURE 11 a typical Speed versus time graph for one shift can be seen (Appendix A). The top of the graph indicates the original speed (1500rpm – 3.77 m/s) of the conveyor (when only 4 sections were loading onto the belt).

Conveyor designers design for certain given parameters. If these parameters change due to a change in the mine planning, the conveyor design needs to be adjusted. If it is a change in capacity, this is achieved by speeding the conveyor-up or slowing the conveyor down. Changing the gearbox ratios normally does this. With the variable speed drives, the powerpack is sourced, taking into account the maximum capacity requirements for a typical 1500-mm conveyor belt. The Drive system is able to supply full torque at lower speed, and a slightly reduced torque at over-speed (the frequency control system enables one you to increase the frequency to 150% of nominal frequency, resulting in a 50% over-speed. If the speed is 3.6 m/s, the conveyor can achieve a speed of up to 5.4 m/s {provided sufficient torque and Power is available})

When unforeseen "Dykes" or geological conditions are being experienced, resulting in additional sections, the flexibility of the drive system (as mentioned above) will allow the mine to adjust its planning. Long delays and loss of production due to the conveyor system not being able to 'cope' with the additional demand can be reduced. Time and effort to change powerpacks to get the correct speed is also now something of the past.

The intelligent system will only allow a certain mass of coal on the conveyor. The mass of coal per meter is therefore being controlled, and the tensions in the belt will be fairly constant. Unnecessary spillage is reduced (reduction in Labour cost); idlers are not overloaded as well as pulleys and structures.

Due to reduced belt speed belt and idler life will be increased.

Original belt speed was 3.77 m/s.

Measure saving of average belt speed to date is 34 %. Therefore average belt speed is 2.49 m/s

Using the belt –life formulae as published in Beltcon 4, the 'theoretical' belt life is:

Belt life at 3.77 m/s = 13.216 million Tons.

Belt life at 2.45 m/s = 30.34 million Tons.

(Expected life in months = calculated life {Tons}/ coal transported {Tons} by belt per month)

Original expected life = 34.585 months

New life expected = 79.4 months.

Belting cost per month = Cost to replace belt / months life expected

Original calculated monthly cost = R 57 000 / month

New monthly cost =R 24 800 / month

This results in a saving of 56% from the original system (theoretical calculation) on belt life.

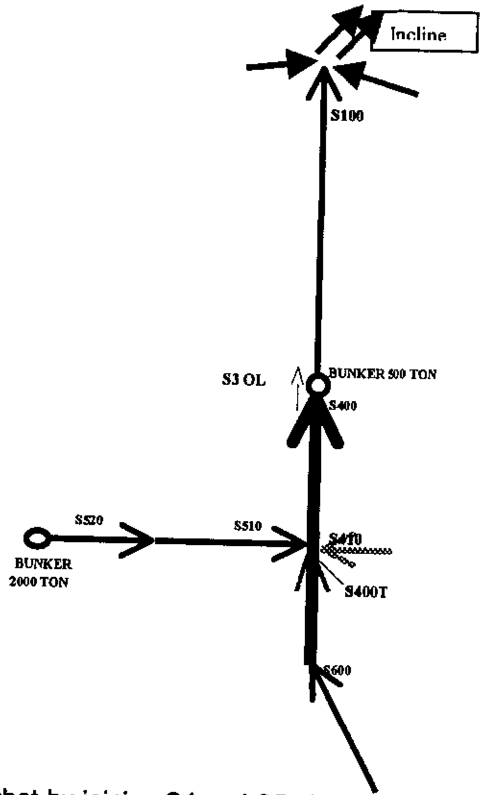
The calculated saving (based on idler shell wear measured), on idlers is in the region of R8 000 per month.

4.2 Case study 2 – Brandspruit South 4 Tripper drive

4.2.1 Background

Brandspruit investigated the possibility to join two conveyors South 4 and South 5 (FIGURE 12). This was done because the drive section of conveyor South 5 had to be moved to accommodate a new conveyor South 410.

FIGURE 12



Calculations showed that by joining S4 and S5, the safety factor dropped below 6.5 - calculated at a friction factor of 2% (see TABLE 5).

Capacity (T/hr)	Power required (kW)	Maximum Tension (run) (kN)	Take-up (run) (kN)	Safety factor (run)
3000	1001.56	301.49	49	6.22
2400	782.24	294.16	48	6.37
1600	504.42	283.68	46	6.61

TABLE 5

This was not acceptable as the minimum safety factor for this installation was decided not to be less than 8 (Solid Woven Belt).

The alternative of installing a tripper drive was decided on.

TABLE 6 shows the calculation summary for the tripper drive installation.

Capacity (T/hr)	Power required at head (kW)	Power required at tripper (kW)	Maximum Tension at head (run) (kN)	Input tension at tripper (Kn)	Take-up (run) (kN)	S f (run)
3000	639	227	231	57	37.25	8.12
2400	508	181	229	57	37.2	8.19
1600	336	121	228	57	37.14	8.24

TABLE 6

4.2.2 Conveyor layout and general specifications

The following graph and table shows the elevation of and the technical specifications of the conveyor

SOUTH 4 & 5

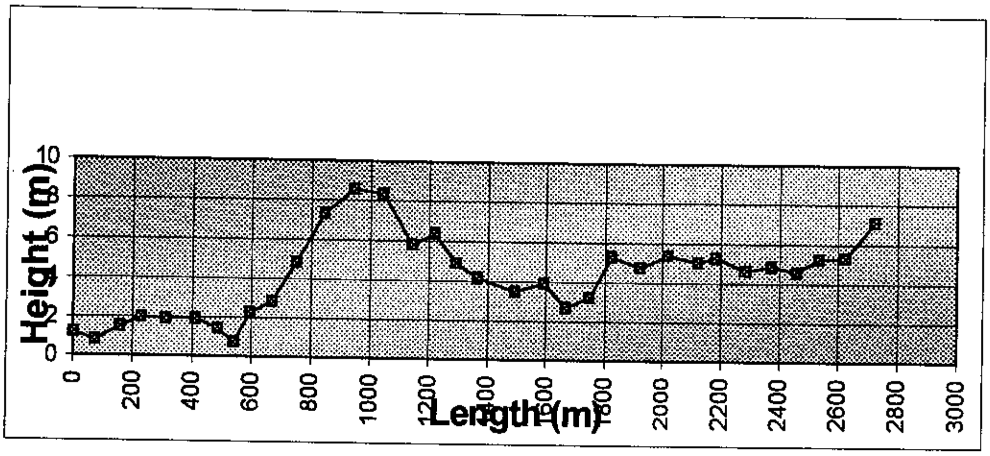
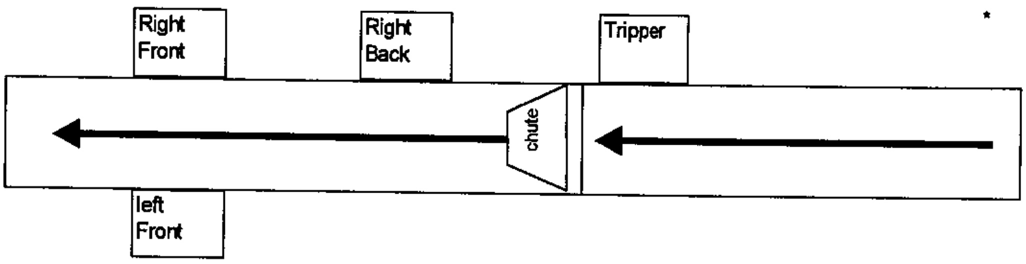


FIGURE 13



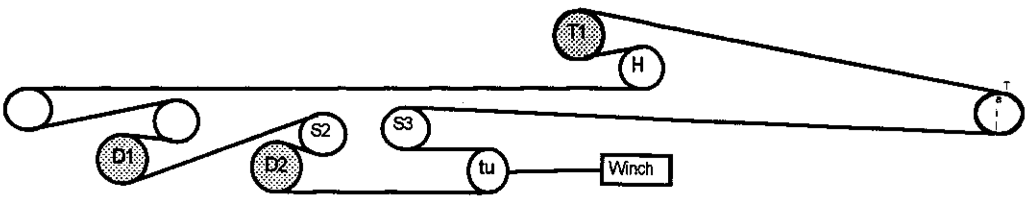


FIGURE 14

		Left front	Right front	Right back	Tripper
gearbox	Make	Hansen	Hansen	Hansen	Hansen
	Ratio	20:1	20:1	20:1	20:1
Motor	Make	WEG	WEG	WEG	WEG
	kW	260	260	260	260
	Voltage	380	380	380	380
Var speed	Make	ABB	ABB	ABB	ABB

Idler spacing (Trough)= 1.8 m
Idler spacing (Return)= 3.6 m
Idler diameter = 152 mm
Shaft diameter = 30 mm

Belt Length= 2721.8 m
Belt width= 1500 mm
Lift = 5.909

Drive system efficiency= 96.7%

TABLE 7

4.2.3. Controlling of the tripper drive

The tripper consists of a drive pulley and a snub pulley. The drive pulley is driven by a 20:1 ratio gearbox and a 260kW motor. The snub pulley is mounted on a hinged frame with load cells attached to the frame (see Figure 15).

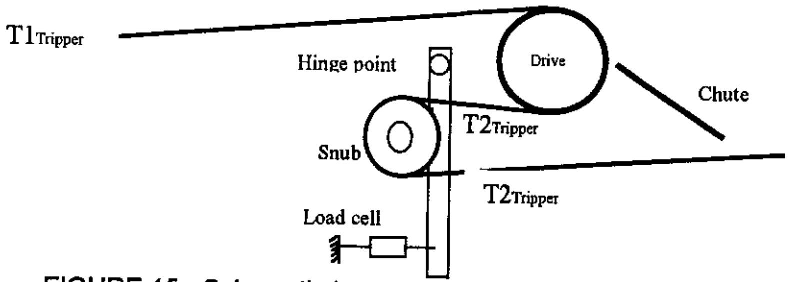


FIGURE 15 - Schematic layout of tripper drive

The calculated tensions for the conveyor can be seen in FIGURE 16 below. Line AB, indicates the tension if no tripper is used (fully loaded belt)

To determine the control limits required at the tripper, the maximum allowed tension line is drawn in. From this figure, it can be seen that the maximum tension at the head will exceed the maximum allowed tension. To overcome this the maximum allowed T2 tripper tension is calculated.

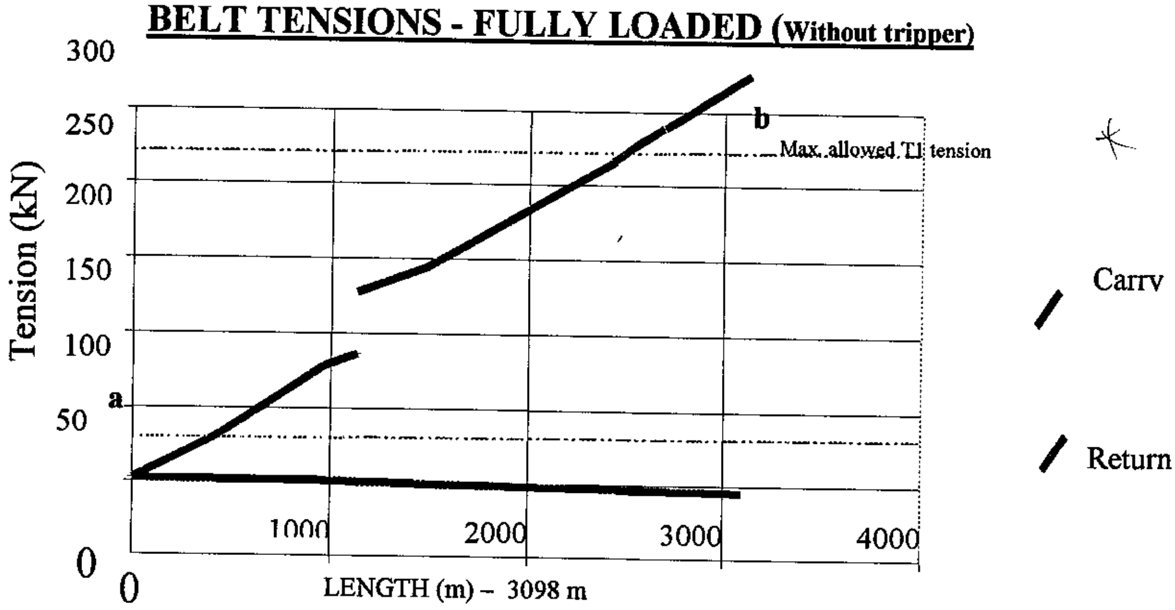


FIGURE 16 (2400 T/hr)

IN FIGURE 17 the calculated control range for the T2 tripper tension is indicated.

These maximum and minimum tensions after the tripper drive (T2 tripper) are now used to determine the settings for the control limits in the PLC.

BELT TENSIONS – Tripper in operation

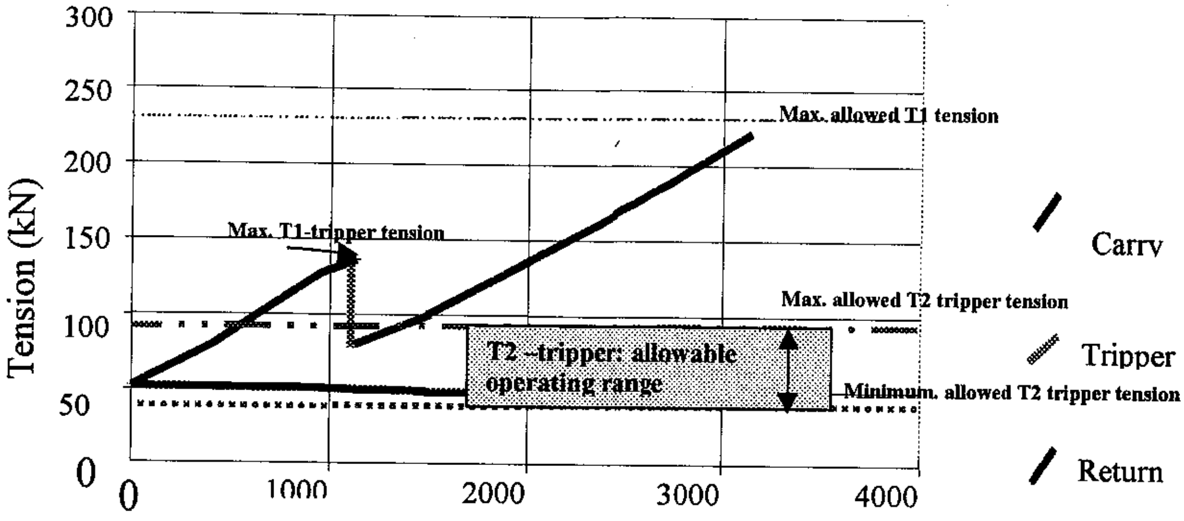


FIGURE 17 (2400 T/hr)

The tripper control is independent of the main drive at the head. The only communication between the main drive and the tripper drive, is a potential free contact from the main drive to tart the tripper drive, and a potential free contact from the tripper drive, to the main drive to stop the main drive if there is a fault at the tripper drive

The load cell tension is converted to a 4 – 20 mA signal with a pre-amp. This signal is sent directly to the ABB VSD panel as a torque reference. If there is an increase of load at the back of the conveyor the T2 tension increase and the drive receive an increased reference.

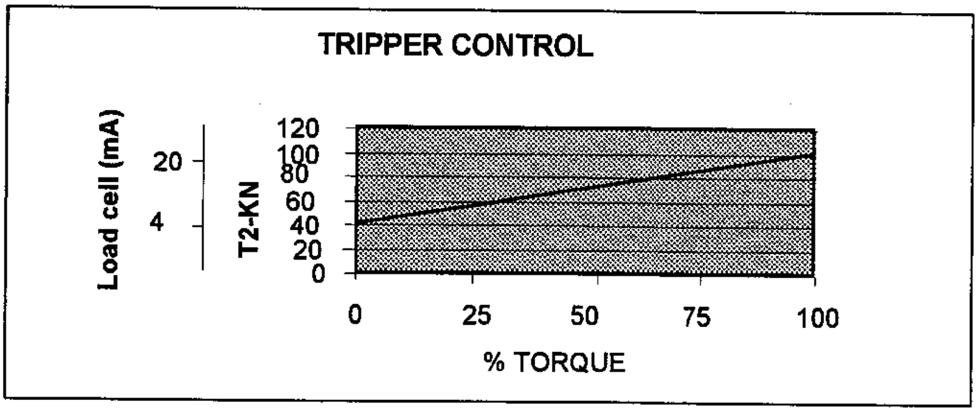


FIGURE 18

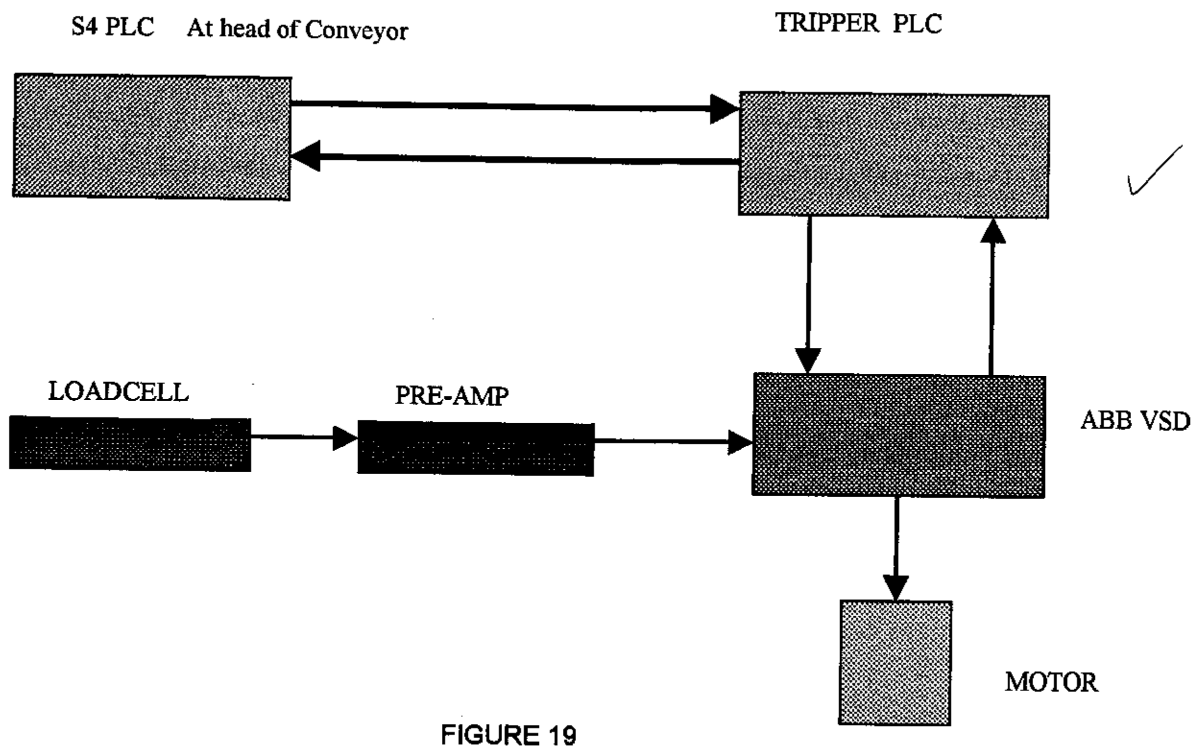


FIGURE 19

4.2.4 Power requirements

Calculations were performed on the power requirements for this conveyor. Indicated in the graph below is the amount of power required for the different capacities. It must be noted that the Tripper power indicated is for a fully loaded conveyor belt. This power is required to keep the conveyor belt safety factor within acceptable limits.

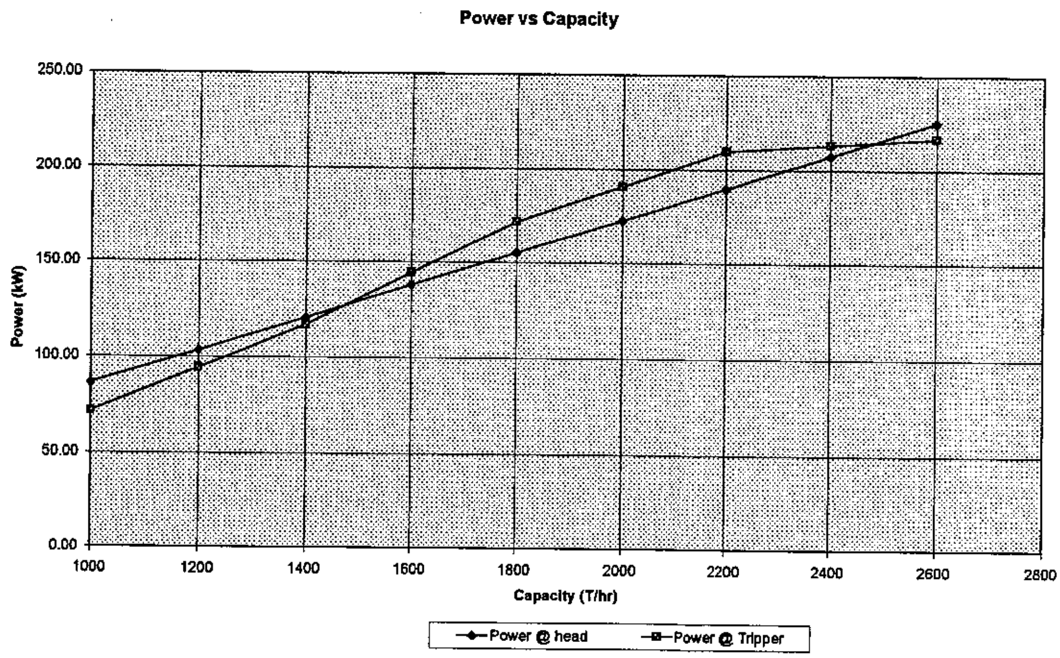


FIGURE 20

It must be taken into consideration that the coal is loaded at different points on the conveyor and that the power input requirements change for the different loading areas.

4.2.5 Capital comparison

Two conveyors were joined to become one conveyor, therefore the cost of one drive system will be compared to install a tripper system.

COST OF ONE DRIVE SYSTEM (1)		COST OF TRIPPER (1)
Framework & Pulleys	715 708	94 060
Power Packs & mechanical items	783 377	193 475
* Elect/Telemetric	726 999	441 310
TOTAL	2 226 084	728 845

* NOTE: Not all electrical/telemetric equipment included. Only major equipment that differs between the two installations.

The tripper cost is therefore approximately 32,7% of the original cost.

Although there is a straight saving in cost, a further operational cost saving is obtained by increasing belt life, idler life, pulley bearing and shell life.

Now taking only belt life in to consideration, the following monthly saving can be obtained.

Original conveyor length (S4) = 1 967 m
Original conveyor length (S5) = 833 m
New conveyor length (Total) = 2 800 m

Using the belt life formulae published in Beltcon 4, the original expected belt life are calculated as follows:

Original calculated belt life for S4 = 13 701 million tons (3,87 m/s)
Original calculated belt life for S5 = 11 098 million tons (2,8 m/s)
New calculated belt life for total belt = 34 733 million tons (2,9 m/s)*
*- Not taking tripper into account
Speed reduced by 25% (assumed). (Measured to date is Minimum of 30 % reduction in speed).

Belt life extra pulleys (tripper) are taken into account (66,7% of original life –not proven method) = ± 23 155 million tons

Therefore original monthly cost for S4 = R57 180/month (37,7 months life)
Original monthly cost for S5 = R29 933/month (30,5 months life)

Estimated new monthly cost for combination = R48 160 (63.7 months life)

Estimated saving % in monthly cost = 44,7%

5. CONCLUSION

Variable speed drives were developed to accommodate high peaks on a conveyor system. During the investigation major benefits such as a reduction in average speed, lower starting tensions, due to a Soft-Start, flexibility in accommodating production variances and the simplicity of drive control were identified.

After four years of operating VSD conveyors, they have been proven to be very reliable and economical. The decision was made at Brandspruit to install VSD drives on variable load conditions, which will contribute in striving towards reducing operating cost on underground conveyor systems.

This technology has many advantages and the authors' feeling is that this drive technology has the potential to grow even further

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CURRICULUM VITAE

Louis Botha matriculated in 1978 and obtained his government certificate of competency as electrical engineer in 1986. He has worked for Amcoal at Cornelia Colliery, New Vaal Colliery and Springfield Colliery, 1983 to 1989, as junior engineer and section engineer. He joined Sasol Coal's Twistdraai Colliery in 1989 and had the position of section engineer and underground manager. He is currently shaft manager at Brandspruit Colliery.

APPENDIX A

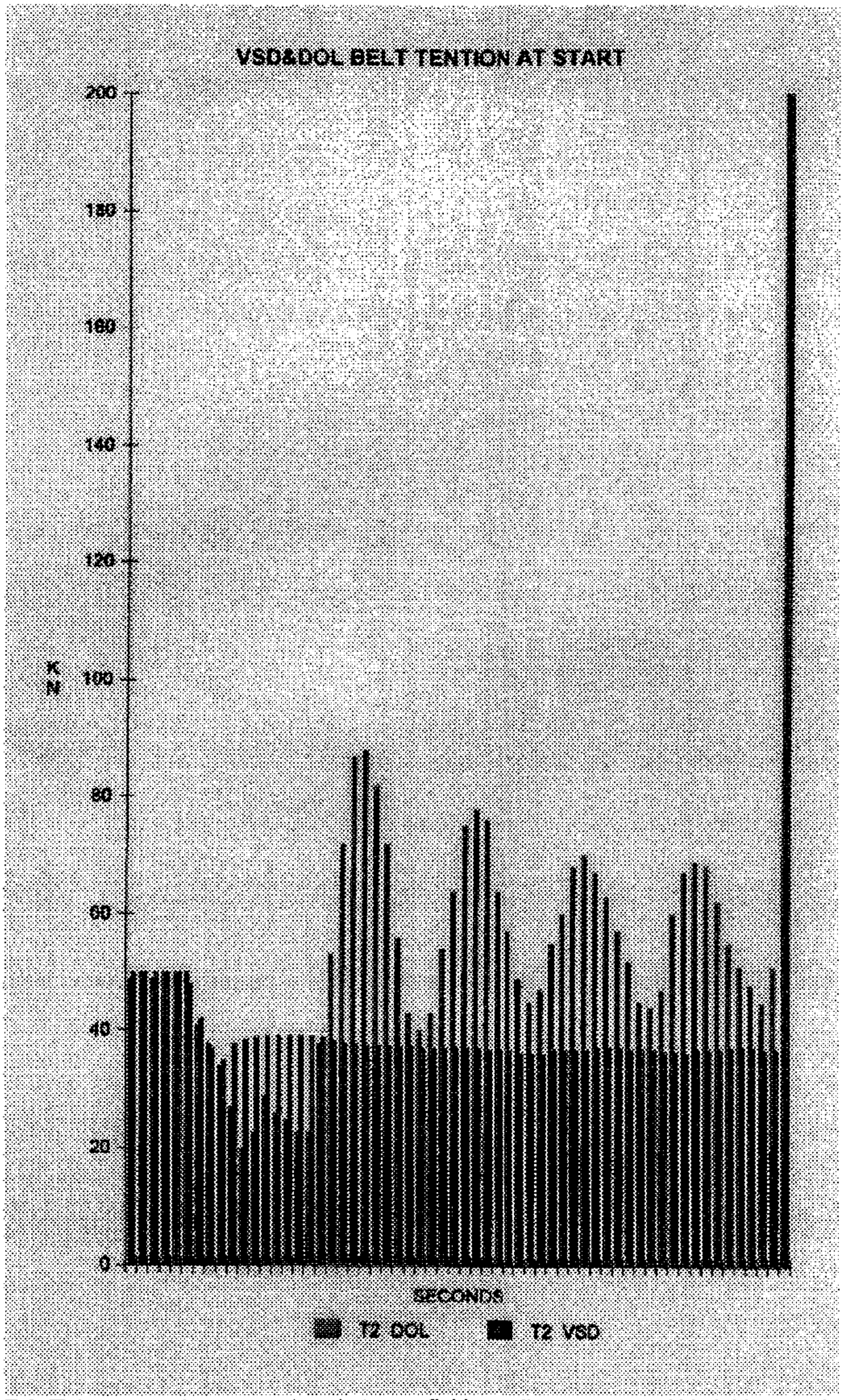

FIGURE 8 (Take-up tension comparison between fluid coupling system and Variable speed Drives)

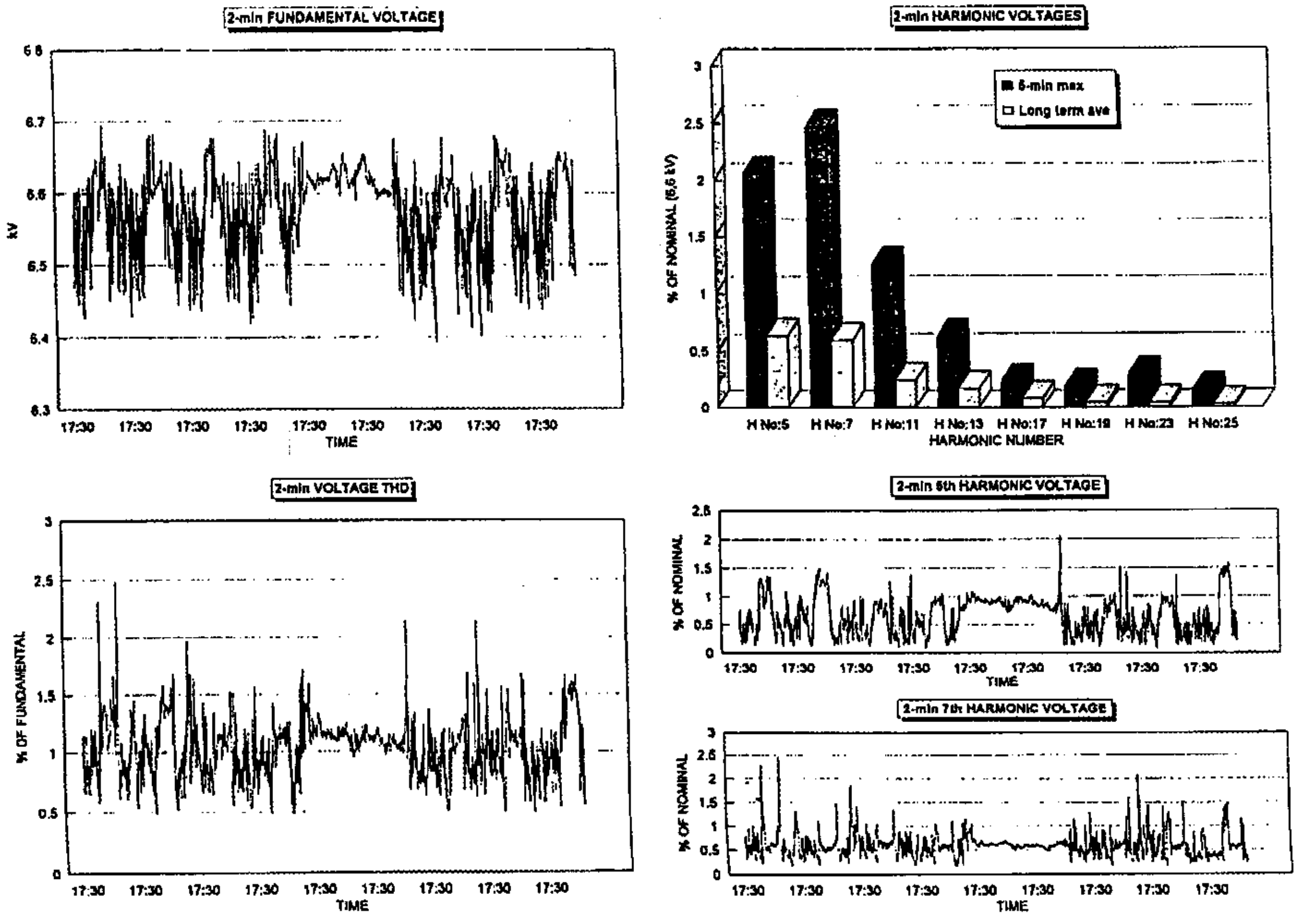

FIGURE 9: WEST 4 SUB. 11 kV SUPPLY - Measured fundamental and harmonic voltages

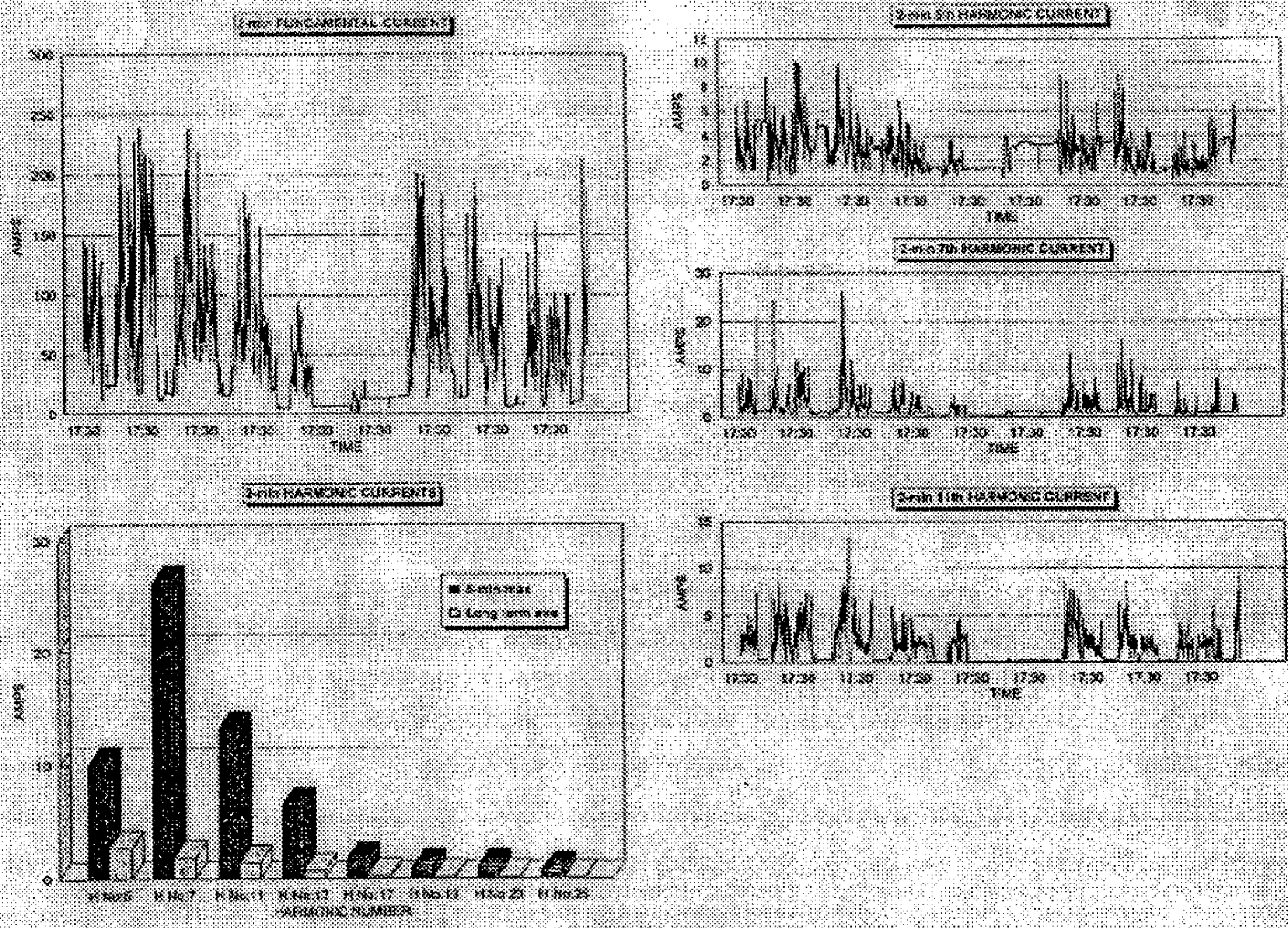

FIGURE 10: WEST 4 SUB. 11 kV SUPPLY - Measured fundamental and harmonic currents

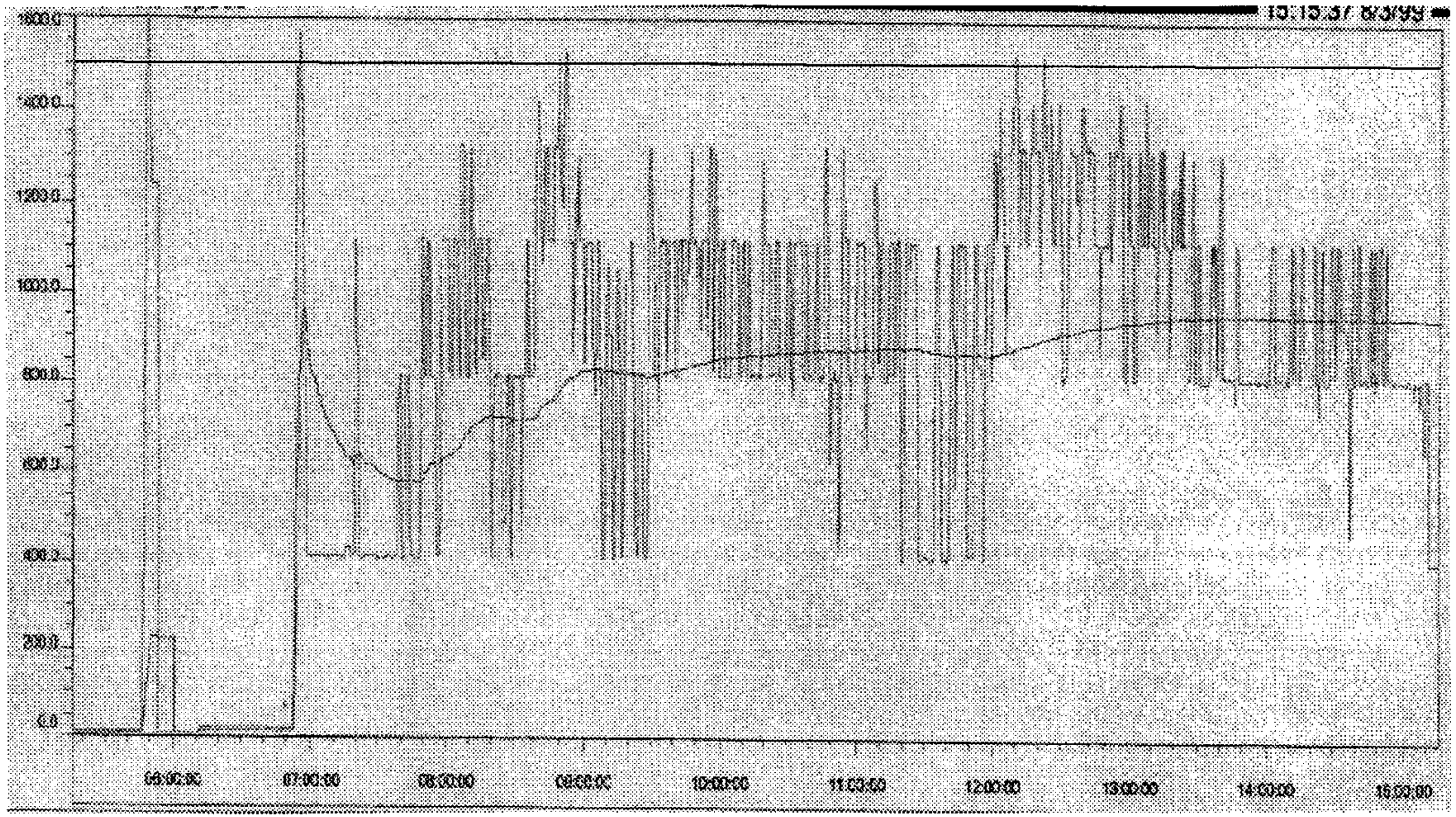

FIGURE 11 (Motor speed variance in one shift)