HYDRAULIC DISC BRAKES WITH INTELLIGENT BRAKE CONTROLLERS FOR BELT CONVEYOR DRIVES

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1. INTRODUCTION

Brake units on belt conveyor drives come in many shapes and sizes, depending on the conveyor design engineer. Anything from basic on/off control over multi-level braking to proportional control has been tried and is also used today.

Svendborg Brakes A/S launched their revolutionary microprocessor based intelligent brake control called SOBO in 1998. The SOBO control principle started as a programmable SOft Braking Option, a deceleration control unit with a simple user interface, but in 1999 Svendborg Brakes released the updated range of intelligent brake controllers with more user-friendly interfaces and with a many more features.

This paper describes the difference between basic hydraulic brake systems and intelligent hydraulic brake systems, and some of the intelligent brake control systems used on belt conveyors over the last four years. A brake is no longer just a brake for us. Being able to manipulate the hydraulics is a very large part of the challenge when stopping a conveyor belt.

It is not the author's intention to question the practice used by conveyor design engineers, as the author does not claim to have the expertise to design a belt conveyor.

What is a hydraulic disc brake?

Illustration 1 - Fail-to-safe dual spring disc brake

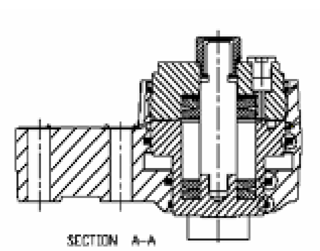

Illustration 2 - Cut through brake caliper half
showing piston, springs, seals, adjusting screw, center bolt

What does a hydraulic system for a brake look like?

Illustration 3 - Compact hydraulic power unit typical for SOBO system

2. BASIC DISC BRAKE CONTROL

The very basic hydraulic disc brake system will consist of a hydraulically released disc brake and a fail-to-safe hydraulic power unit (see ill. 4).

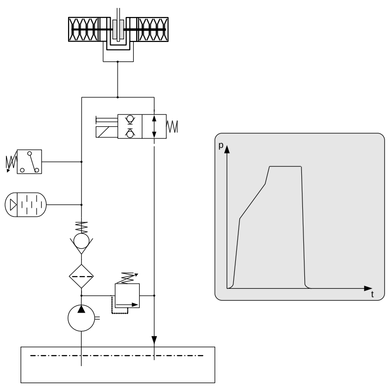

Illustration 4 – Basic fail-to-safe hydraulic brake system

The brake is set and released from the Main Conveyor Control (MCC). In the case of a power failure, the hydraulic system will immediately discharge the oil to the reservoir and the brake will engage will full force.

There are ways to restrict the flow and slowly increase the braking torque over a non-linear ramp, mainly to avoid stretching the belt or damaging other important parts of the conveyor. But still, these hydraulic brake systems would only be used on relative short and stable conveyor.

The basic hydraulic brake system can be adapted for use with belt conveyors by adding features to apply torque in two or more steps, either as an automated hydraulic function or with one or more solenoid valves operated from MCC (see ill. 5).

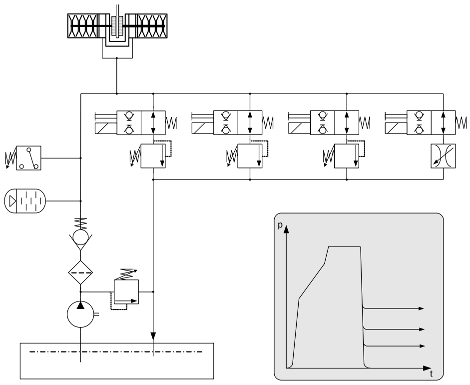

Illustration 5 – Multi stage fail-to-safe hydraulic brake system.

It is up to the conveyor design engineer to choose the braking system on the basis of dynamic analysis modeling to determine starting and stopping problems with the conveyor, taking into consideration the conveyor profile and curves and, of course, the drive system.

Stopping a single overland conveyor or uphill conveyor is not the worst challenge for the conveyor design engineer. But things start to get interesting with the downhill conveyor and also with more overland or uphill conveyors connected in series.

Hydraulic systems with orifices and adjustable relief valves are some times used on smaller belt conveyors to limit the dynamic torque applied during the stopping sequence. A system developed by Svendborg Brakes (ill. 6) includes a hydraulic timer which will set the brake with full torque after approx. 15 seconds, but temperature variations affect the hydraulic timer function so badly that the hydraulic timer can vary more than +/- 25%.

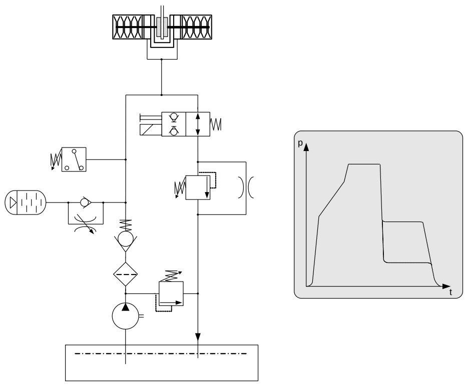

Illustration 6 –Two stage fail-to-safe hydraulic brake system with hydraulic timer

A similar system (see ill. 7 and 8) is used on an uphill belt conveyor at Middelburg Mining Services in South Africa, installed by Svendborg Brakes A/S for Bateman Engineering in year 2000. The 3 km long uphill conveyor was part of a 14 km installation that transports 1800 tons/hour coal on a 1050 mm wide belt at 5 m/sec.

Illustration 7 – Uphill belt conveyor at Middelburg Mining Services with BSFH350 MS brake and two-stage hydraulic system

Illustration 8 – BSFH350 MS brake and two-stage hydraulic system installed at Middelburg Mining Services

At Middelburg Mining Services the pre-set dynamic torque can be adjusted from 100 to 25% and can be held at that value for as long as required, until the brake is set with full torque by energizing a separate solenoid valve.

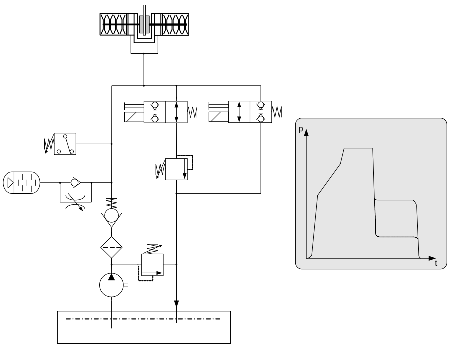

Illustration 9 – Two-stage fail-to-safe hydraulic system with <u>remote full torque valve</u> installed at Middelburg Mining Services

All the previously shown hydraulic disc brake systems have no internal reference to retardation - every time the brake releases or engages it is controlled by the MCC. And not much else can be controlled.

A hydraulic disc brake can be powered by a hydraulic system with proportional pressure regulation, but the proportional regulation needs an external reference - in this case the ideal reference is the belt or shaft speed. By means of a relative small PLC it is possible to control the deceleration (see ill. 10).

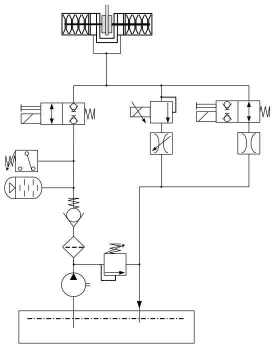

Illustration 10 - Fail-to-safe hydraulic system with proportional pressure control

Svendborg Brakes has taken the proportional brake control a step further with the introduction of the Soft Braking Option some 5-6 years ago. Tests performed with proportional hydraulic valves on brake systems have shown that because the valve accuracy needs to be high, the proportional valves are also extremely sensitive to contamination of the hydraulic circuit. Small dirt particles can completely change the control scheme and failure can cause unbelievable damage to the conveyor.

The SOBO closed-loop proportional control of today is based on Pulse Width Modulation. A powerful technique for controlling analog circuits with a processor's digital outputs. PWM is employed in a wide variety of applications, ranging from measurement and communications to power control (electric heaters, motor power, battery charging etc.).

The PWM output of the SOBO controller will modulate (energize and de-energize) the two SOBO solenoid valves in the hydraulic system.

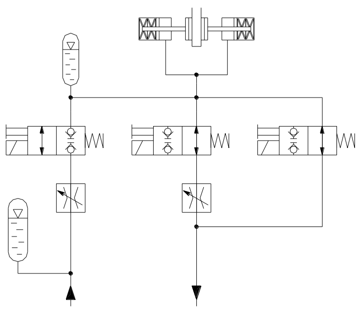

Illustration 11 - Hydraulic diagram for SOBO regulation
for a fail-to-safe spring applied brake

The two solenoid valves will switch once (each) per PWM cycle. And with a PWM cycle time of 200 mS they will switch up 5 times per second, if necessary.

Without the two throttle valves mounted at the solenoid valves, the hydraulic pressure would jump from one limit to the other very fast. The throttle valves in combination with the bladder accumulator mounted on the brake line, gives a good regulation for most applications, especially for belt conveyors.

The solenoid valves used on Svendborg Brakes hydraulic systems are high quality components (Hydac or equal). You can expect a reaction time from a high quality solenoid valve of 25 - 40 mS and with the time required for the SOBO controller to process data and calculate settings, the opening or closing time will be approx. 50 mS.

3. INTELLIGENT BRAKE CONTROL SYSTEMS

What conveyor designers and operators don't want is to immediately apply the brake with full force and hold it during the complete (short) stopping sequence. In most cases this will give excessive wear on gear reducers, bearings and belt - and it can easily result in stretching of the belt.

Most design engineers and operators prefer to see is a deceleration ramp shaped like an S with a smooth parking at the end of the ramp. Illustration 12 shows the difference between the two stopping methods.

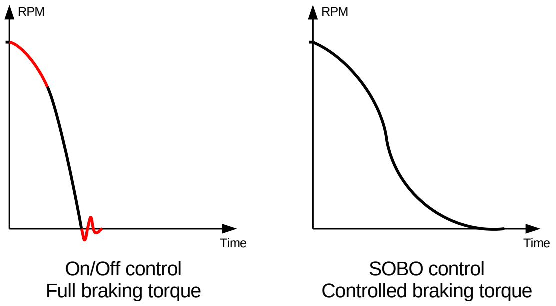

Illustration 12 - Deceleration without SOBO control (left) and with SOBO control (right)

The SOBO controller works with closed loop control (ill. 13 and 14) with reference to the shaft speed, measuring the speed via an encoder or a proximity switch several times per second and comparing the actual speed with the desired speed.

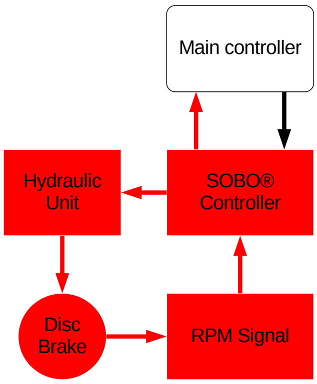

Illustration 13 - Closed loop proportional control

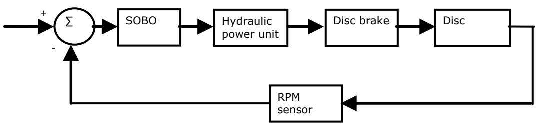

Illustration 14 - Closed loop proportional control

The desired speed is in this case a deceleration ramp programmed into the SOBO controller.

The deceleration ramp (ill. 15) has a deviation band - an upper and a lower deviation limit - and the PWM output will depend on where the actual speed is plotted in relation to the desired ramp during the stopping sequence.

One of the nicest features of the system is that the deceleration ramp - the desired ramp - can be programmed into the control system by the operator. Programming or adjustment can take place on site and without the need for a laptop.

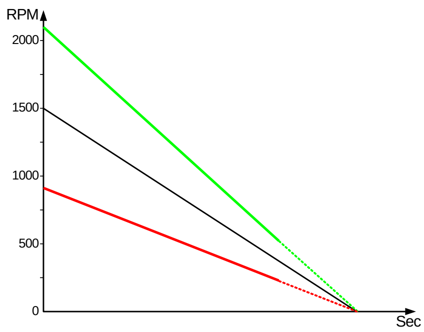

Illustration 15 - Deceleration ramp with desired ramp starting from 1500 rpm, the upper and lower deviation limits at 40% deviation

If, for example, the actual speed is lower than the desired value on the deceleration ramp, the PWM output of the SOBO controller will reduce the braking force.

If the actual speed is higher than the desired value on the deceleration ramp, the PWM output of the SOBO controller will increase the braking force.

If the actual speed follows the desired deceleration ramp (in this case the straight line from 1500 to 0 RPM), the PWM output of the SOBO controller will modulate the brake with a neutral setting which will not change the braking force.

The regulation is based on a formula with the input parameters:

- Δt (time)
- Actual RPM value (RPM sensor)
- RPM deviation limits

The formula can best be described as something that looks like this (ill. 16)

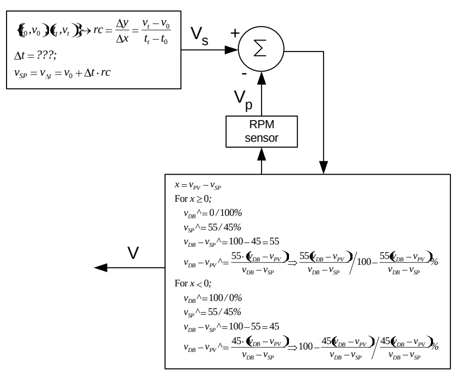

Illustration 16 - Software model of the SOBO regulation principle

Two of the most helpful parameters in the SOBO deceleration are the parking sequence and the minimum deviation.

As the speed reduces during the deceleration process, the deviation band becomes smaller and smaller and the regulation becomes more and more rough. The minimum deviation parameter allows the operator to increase the deviation at low RPM to give a more soft regulation.

When the drive has been brought to a complete stop, the SOBO controller must park the drive with a higher brake force than during the deceleration process, in order to make the system safe. But how does the control system know that the drive has been brought to a stop - it is not possible to measure zero speed.

Svendborg Brakes has defined a parameter called “artificial 0 RPM” - a value at which the control system will consider the drive almost stopped and at which the SOBO controller will initiate a predefined parking sequence.

The parking sequence ensures that the drive is always brought to a soft stop.

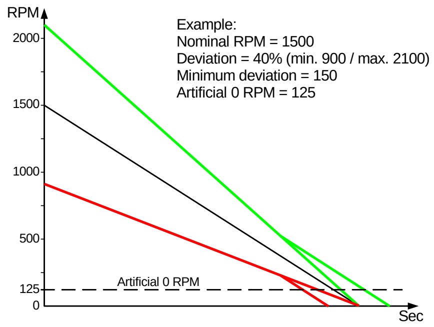

Illustration 17 - artificial 0 RPM

The measuring interval or the regulation interval (the same) is an adjustable parameter in the SOBO controller. So is the PWM cycle.

The shorter the PWM cycle the operator wants, the shorter the regulation interval needs to be. Tests have shown that 2-6 regulation intervals per PWM cycle are sufficient.

The regulation process with a 50 mS regulation interval and a 200 mS PWM cycle can best be described as shown in illustration 18 here under.

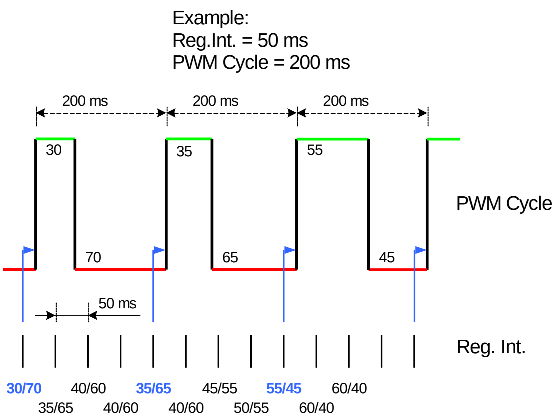

Illustration 18 - Pulse Width Modulation in the SOBO controller

The hydraulic diagram (ill. 19) shows a complete SOBO circuit for a typical belt conveyor.

Next to the two SOBO solenoid valves are:

- Emergency solenoid valve, full torque with throttle valve
- Combined maximum pressure and Quick Brake Contact solenoid valve

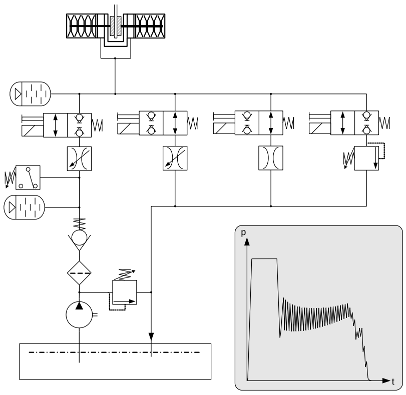

Illustration 19 - SOBO fail-to-safe hydraulic system
Graph showing the hydraulic pressure vs. time when releasing and setting the brake

4. TESTED SOBO BRAKING SYSTEM AT THE HENDERSON MINE, COLORADO

Man Takraf built and commissioned two large overland belt conveyors for the Henderson Mine in 1999-2000. The largest of the two belt conveyors is 16.8 km in length and is a combined overland and uphill profile (3 degree incline) with a capacity of 2500 tons/hour Molybdenum ore running at 6.1 m/sec belt speed.

The Henderson Mine is located 2800 m above sea level in the Rocky Mountains.

Illustration 20 - overland belt conveyor at the Henderson Mine

The 16.8 km belt conveyor is driven by 4 large 2 MW motors with Falk gear boxes. The 4 drives used to have basic two-stage brake systems with a hydraulic timer, but this kind of brake control was not accurate enough for this conveyor, so the mine upgraded all 4 drives with SOBO control in 2001.

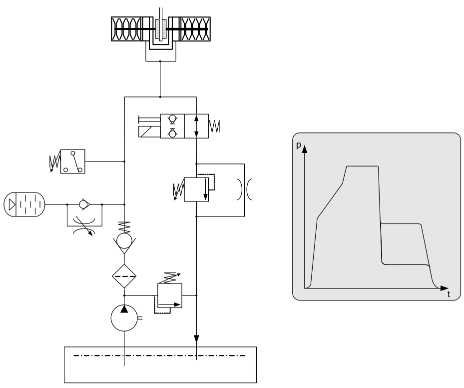

Illustration 21 - two-stage fail-to-safe hydraulic system with hydraulic timer

The complete SOBO brake system upgrade installed in 2001 consists of:

- 4 BSFH300 dual spring brakes
- 4 Hydraulic units
- 1 Common SOBO control system with two SOBO controllers for redundancy

At that time our SOBO technology was not as good as it is today - we admit this. But the system has been running now for 4 years without any problems.

The SOBO control system is programmed to bring the 16.8 km belt conveyor to soft stop in 29 seconds. This proved to be the shortest possible stopping time when the upgrade was commissioned. Any attempt to try to shorten the stopping time would cause the belt to slip on the drive pulleys.

But 29 seconds is actually a fantastic (short) stopping time for a 16.8 km belt.

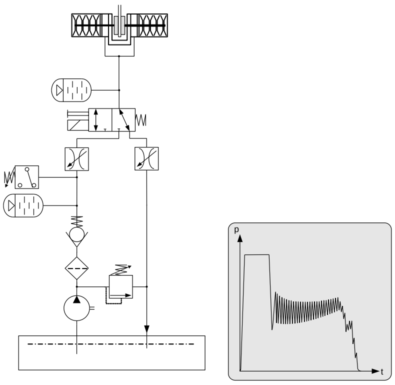

Illustration 22 - 2000 version of SOBO fail-to-safe hydraulic system with a 3/2 valve

We have learned today that the 3/2* SOBO valve tends to leak in the change-over from one position to the other. This leak rate has some influence on the stability of systems with relative short stopping times (for example escalators and wind turbines), but not so much influence of belt conveyors as they usually have relative long stopping times.

*(3 = number of valve connections, 2 = number of valve positions)

Therefore we have upgraded our SOBO hydraulics to the system with two 2/2 SOBO valves (ill. 19 and 23). First of all this solution is much more reliable, but it is also easier to adjust and fine tune.

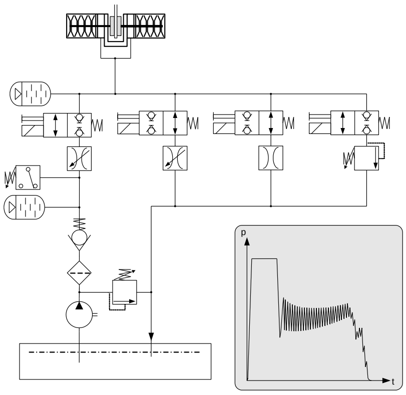

Illustration 23 - SOBO fail-to-safe hydraulic system
Graph showing the hydraulic pressure vs. time when releasing and setting the brake

The SOBO brake systems on the 16.8 km Henderson belt conveyor will be upgraded this summer (2005) with the new hydraulic design.

The SOBO control system consists of two SOBO controllers in a redundant setup, with battery power backup that can feed the SOBO control system and the hydraulic valves in case of power failure (ill. 24). It is very important for the belt conveyor life time that the brakes do not engage with full force in any situation.

Any braking sequence on this belt conveyor will always be under full control, and in the event of a SOBO controller failure, the redundant setup will automatically change over from the un-healthy controller to the healthy controller - also during a stopping sequence.

Illustration 24 - The SOBO control system with two SOBO controllers and battery power backup

After commissioning of the SOBO brake system in 2001, the operators at the Henderson Mine documented the 29 seconds stopping time (ill. 25).

Illustration 25 - Speed vers. time deceleration ramp logged by the operators at the Henderson Mine for documenting the 29 sec. stopping time

5. THE LATEST IN SOBO BRAKING - SHADOW BRAKING - ESCONDIDA, CHILE

Shadow Braking is a new SOBO braking principle released in 2004 by Svendborg Brakes, in response to the need for backup braking - and as an alternative to redundant SOBO systems.

The Shadow Braking principle uses two SOBO brake systems (see ill. 26) to control the stopping sequence in parallel - one acting as the primary braking system, with the controller programmed to regulate the desired stopping sequence - and the other as backup or secondary braking system, with the controller regulating its own independent stopping sequence.

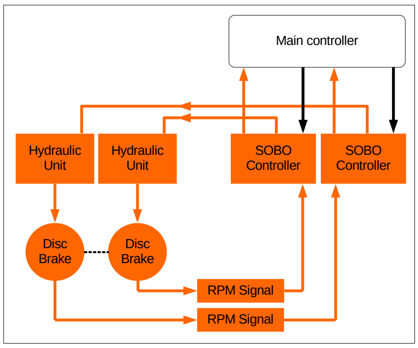

Illustration 26 - Shadow Braking closed-loop control

Under normal conditions, only the primary brake system regulates the braking sequence.

The Shadow Braking principle is, amongst others, used on conveyor 200-CV-2C at a very recent delivery to the customer Minera Escondida in Chile, for the Escondida Norte expansion.

The equipment is supplied via Man Takraf Fördertechnik in Germany,

The conveyor 200-CV-2C is 6.3 km in length and the drive system consists of two 2 MW drive motors with Flender gear boxes Each drive has two brake discs with two disc brakes and two hydraulic power units (ill. 27).

On each of the two drives, one hydraulic power units controls the service brakes (for normal operation) and one controls the emergency brakes (for shadow braking).

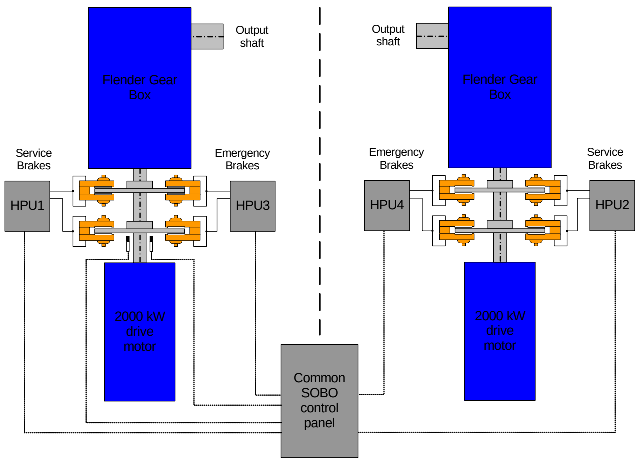

Illustration 27 - Drive and brake system for conveyor 200-CV-2C

All the disc brakes on the conveyor are controlled from one common SOBO control panel. Normal deceleration or stopping sequences are controlled by a single SOBO controller which regulates the primary brake (service brake).

Te other SOBO controller is programmed for Shadow Braking, i.e. regulation of the backup brake (emergency brake), but only if the primary brake fails to control deceleration.

A SOBO RPM Monitor validates and monitors the speed signals to ensure that a simple sensor failure does not lead to loss of control.

Illustration 28 - two SOBO V4 controllers for Shadow Braking

Shadow Braking example 1:

The primary SOBO controller and its disc brake regulate the stopping sequence within the SOBO controller's deviation band.

The actual RPM value follows the desired ramp (more or less) and does not infringe on the deviation band of the secondary controller.

The secondary backup brake system will only cut in if the primary system fails to control the deceleration on its own.

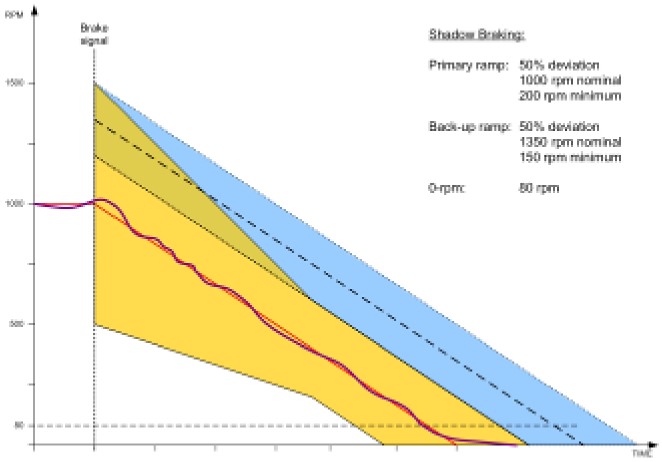

Illustration 29 - Shadow Braking ramp and deviation limits - normal condition

Shadow Braking example 2:

The primary SOBO controller is unable to regulate the deceleration within its deviation band, causing the actual RPM value to infringe on the deviation band of the secondary SOBO controller in the lower deviation range. The primary disc brake (service brake) cannot control the situation.

The Shadow Braking function will activate, causing the secondary brake to apply controlled force.

The primary brake will not apply full force.

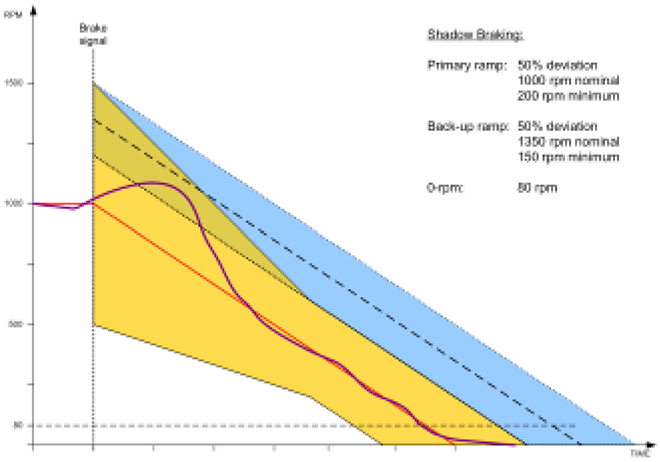

Illustration 30 - Shadow Braking function activated for short period of time

Shadow Braking example 3:

The primary SOBO controller is unable to regulate the deceleration within its deviation band, causing the actual RPM value to infringe on the deviation band of the secondary SOBO controller in the higher deviation range.

The Shadow Braking function will activate, causing the secondary brake to apply controlled force.

The primary brake will apply full force for a given period of time.

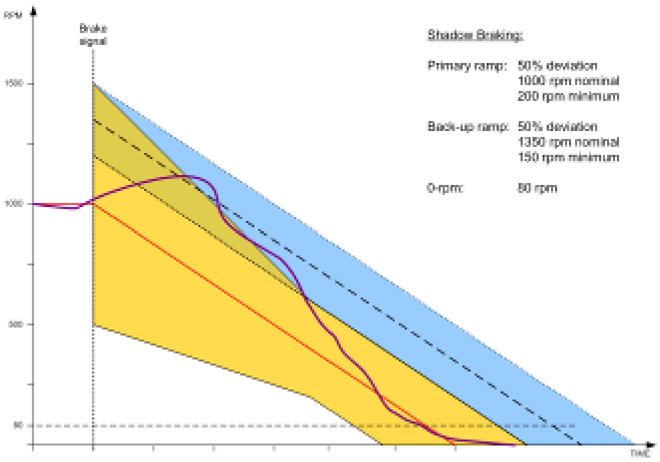

Illustration 31 - Shadow Braking function activated for longer period of time

6. CONCLUSION

Svendborg Brakes have come a long way with intelligent braking solutions since 1999 by investing in testing and continuous development. Today Svendborg Brakes is the leading supplier of intelligent and programmable braking systems in this class - our SOBO controlled braking systems are used on belt conveyors, escalators, winches, mine winders, wind turbines, drill rigs, etc.

The fact that Svendborg Brakes SOBO controlled braking systems can be programmed and adjusted on site, by the operator and without the need for a laptop, makes them very unique.

With the introduction of the Shadow Braking, we have taken intelligent braking one step further. The Escondida Norte conveyors are scheduled for commissioning during the second quarter of 2005 and the author hopes to deliver some (verbal) results for this presentation.

Our customers ask for maximum safety.

Being able to brake and stop conveyors is about safety - safety is our business.

7. AUTHOR'S CV

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