STARTING CONSIDERATIONS FOR CONVEYOR APPLICATIONS WHEN USING SLOW SPEED WINCHES

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1. INTRODUCTION

This purpose of this paper is to review the approach for quantifying the correct starting tension levels in conveyor systems where tensioning is by means of slow speed automatic winches necessitating fixed tension starting, typically in conveyors of length 500 m to 2000 m. The loading condition of the installation will be noted and the procedure for quantifying tension settings during starting will be the primary objective of this paper. Running tensions utilising slow speed winches are considered not to be problematic and hence does not warrant discussion.

Consideration will also be given to reviewing the variables relevant to PVC, ply and steel cord belting with specific reference to the Funke line. In the final analysis the various types of fluid couplings and belting types will be put into perspective when using slow speed winch applications during starting. Due to the fact that this aspect has to a certain extent been partly dealt with in previous Beltcon papers, it is considered to be the secondary objective of this paper.

2. ASSUMPTIONS

This paper was developed on the basis that it will not be necessary to review the principles of basic conveyor design. It is assumed that the reader is conversant with the basics of the subject.

Reference is made in this paper to what is commonly referred to as being the Funke line. This, in essence, refers to work done by Dr Funke on the dynamics of tension waves in conveyors. Dr Funke is associated with the University of Hannover in Germany. In this paper only certain aspects of his work will be highlighted on with the understanding that the reader may pursue the matter should further information be required. It is assumed that the reader will accept the references made in the paper on face value in view of the aforesaid.

3. DISCUSSION

The discussion section of the paper is structured such that all the various elements leading up to the calculations are noted first. These elements are not discussed in any chronological order and the sequence is coincidental. Attention is given to the types of fluid couplings, the Funke line, tension diagrams and finally the calculations for determining the starting tensions for these applications.

- **FLUID COUPLINGS**

Fluid couplings come in various shapes and sizes. In the fixed fill range of fluid couplings the industry distinguishes between a basic traction, delay fill, extended delay fill and soft start type couplings. These can be classed as the basic units.

The more sophisticated range of units is the variable fill fluid couplings and these also come in various shapes and sizes. In essence the oil levels in these couplings are externally controlled by means of scoop tubes and hydraulic pumps and/or a combination of these. The different types do not have a bearing on this discussion and one only needs to take cognisance of the fact that the torque transfer rates are essentially proportional to the absorbed power conditions in the system at any point in time. For this reason they have all been grouped as a single line item reflecting the relevant start factor as 1,15 on the absorbed power for all applications.

The starting factors for all the various types of standard fluid couplings in the industry are noted in the following table.

TABLE OF STARTING FACTORS		
Coupling type	**Starting factor**	**Value of power level**
Basic traction coupling	**1,8 to 2,0**	Installed power
Traction coupling with a delay fill chamber	**1,6 to 1,8**	Installed power
Traction coupling with an extended delay fill chamber	**1,4 to 1,6**	Installed power
Traction coupling with an extended delay fill chamber plus annular ring	**1,4 max**	Installed power
Variable fill couplings	**1,15**	Absorbed power

Table 1 Starting Factors

The understanding that must be associated with the above table is the following:
When an electric motor starts from a mechanical engineering perspective, it will draw all the current that it can handle in order to get from zero speed to full speed. The resulting starting torque that can be produced by an electric motor starting direct on line will normally be at least equal to 2,5 times full load torque. Simplistically put, the purpose of the fluid coupling is to limit the high transmittable torque from the motor to the conveyor to the values noted in Table 1.

A fluid coupling can be suitably trimmed for any specific application. This is achieved by varying the volume of oil in the working circuit of the coupling. To this end the fluid coupling of a 75 kW motor can be trimmed such that it will only transmit the equivalent torque of say 68 kW of the available 75 kW. For purposes of this discussion, the installed power is then considered to be 68 kW.

In practice it can be said that a fixed fill coupling will start with some level or volume of oil in the working circuit while the variable fill couplings will start with no oil in the working circuit.

As a rule applicable to fixed fill fluid couplings, it can be stated that there is a direct relationship with the installed power. This is irrespective of whether the system is running full, empty or anything in between.

The rule applicable to a variable fill coupling is that there is a direct relationship with the absorbed power required to drive the system. The variable fill coupling is sensitive to the level of absorbed power required and differentiates between the empty, full or anything in between power and torque requirements.

That should adequately clarify the values noted in the tables. So much for fluid couplings, what about the Funke line?

- **FUNKE LINE DETAILS**

As a statement of fact, a conveyor belt is not a rigid body. The belt will respond to variances in tensions along its length by stretching and contracting in accordance with the forces being applied and released. As tension is increased it will stretch and as this tension is decreased it will thus reduce in length accordingly.

A conveyor installation can also be described as an endless length of conveyor belt where the actual belting is effectively or fondly referred to as being a “piece of elastic”. In a closed loop system like this, it is inevitable that the piece of elastic will be subjected to localised stretch conditions as induced when the system is in the driving mode. As the drive is powered, the tension local to the drive pulley will be increased and the tension along the length of the belt will be increased in accordance with the resistances which are progressively encountered.

The essence here is that there must be a variation in tension along the length which in turn will be redistributed at a specific rate over the entire conveyor belt in the system. Needless to say, the redistribution speed of the tension variance will be governed or controlled by the material used in the construction of the conveyor belt. Typically there will be a difference between a steel cord, multiply and mono-ply belting.

With reference to the work done by Dr Funke, he quantified the speed at which the tensions will be redistributing along the length of an empty conveyor belt to the values noted in the table below.

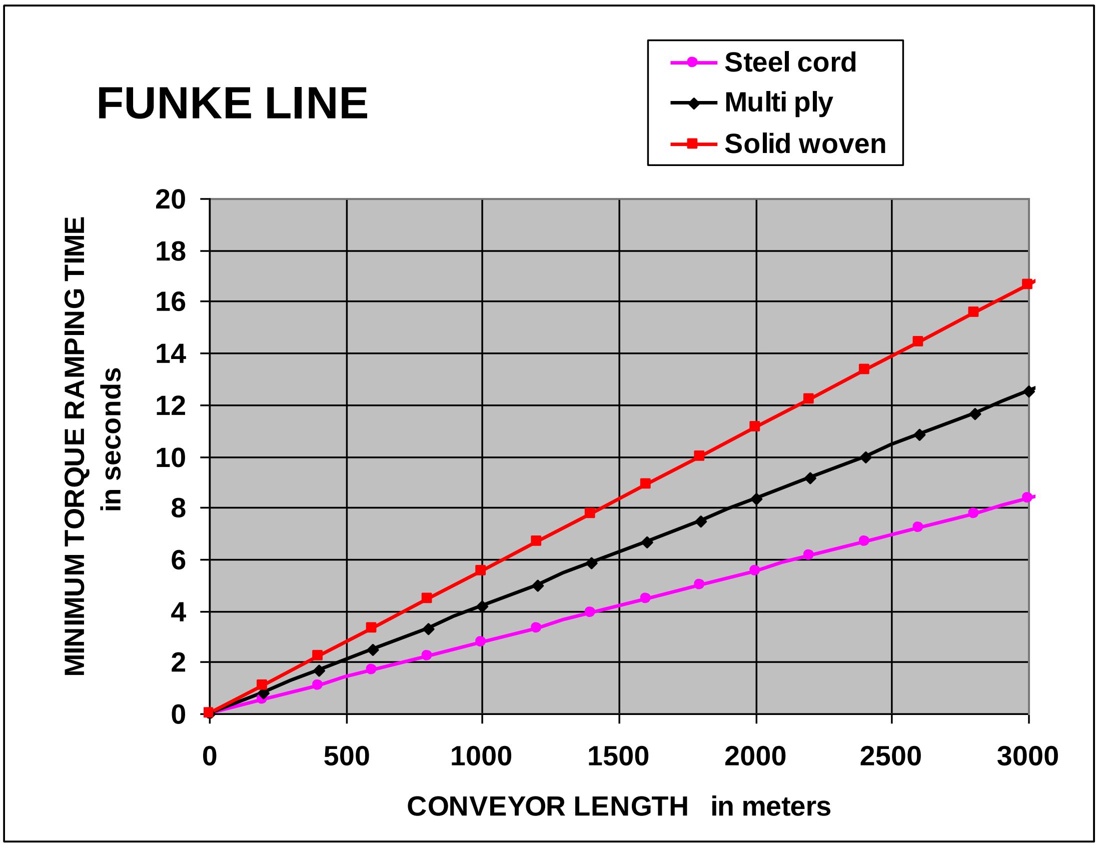
TENSION REDISTRIBUTION SPEED TABLE	
Belt construction	Redistribution speed
Steel cord	1800 m/s
Multiply belt	1200 m/s
Solid woven belt (PVC)	900 m/s

Table 2 Tension redistribution speed

The ramping time from zero acceleration torque to maximum acceleration torque must be at least five times the time it takes for a disturbance to travel from the head end to the tail end of the conveyor in the return belt.

$$\textbf{Torque Ramp Time} = \textbf{5 x} \frac{\textbf{Conveyor Pulley Centres}}{\textbf{Tension Redistribution Speed}}$$

From the aforesaid the following graph was developed and this is referred to in the industry as being the Funke line.



Graph 1 the Funke line

- **TENSION DISTRIBUTION DETAILS**

The best way to understand anything is to look at it simplistically. For this purpose a horizontal conveyor is reviewed that is generally flat.

TABLE OF TYPICAL TENSION VALUES

Conveyor length:	**2000**	m
Conveyor lift:	**10**	m
Belt speed:	**3.62**	m/s
Belt capacity:	**1800**	TPH
T2 tension running:	**20**	kN
Effective tension on return strand:	**8.1**	kN
Tail tension:	**28.1**	kN
Effective tension troughing strand:	**16**	kN
T1 tension empty:	**44.1**	kN
T1 tension full:	**119.9**	kN
Effective tension material:	**75.8**	kN
Absorbed power empty:	**87.242**	kW
Absorbed power full:	**361.638**	kW
Installed power:	**2 x 240**	kW

Table 3 Typical tension values

From the above information the tension graph (Graph 2) of the conveyor is developed and constructed. The take-up of the conveyor is considered to be immediately behind the drive at the head of the conveyor. The graph then starts on the return strand with the T2 take-up tension value. It continues along the return strand and increases in value to overcome the resistances in the return strand of the conveyor. After reaching the tail it now increases in value to overcome the resistances in the troughing strand up to the drive which is at the head pulley of the conveyor.

On the graph the take-up and start of the return strand is on the left hand side. It increases in value from left to right to the centre of the graph where the tail pulley values are located. From the centre it increases in value toward the right where it terminates at the head pulley value.

Only two loading conditions are observed, the empty belt and full belt conditions. The same procedure may be followed for variations as a result of other load conditions that the reader may want to examine.

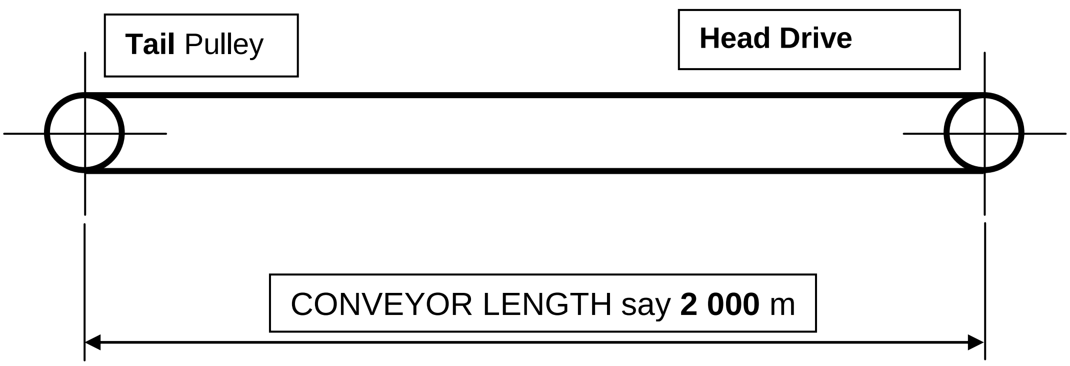
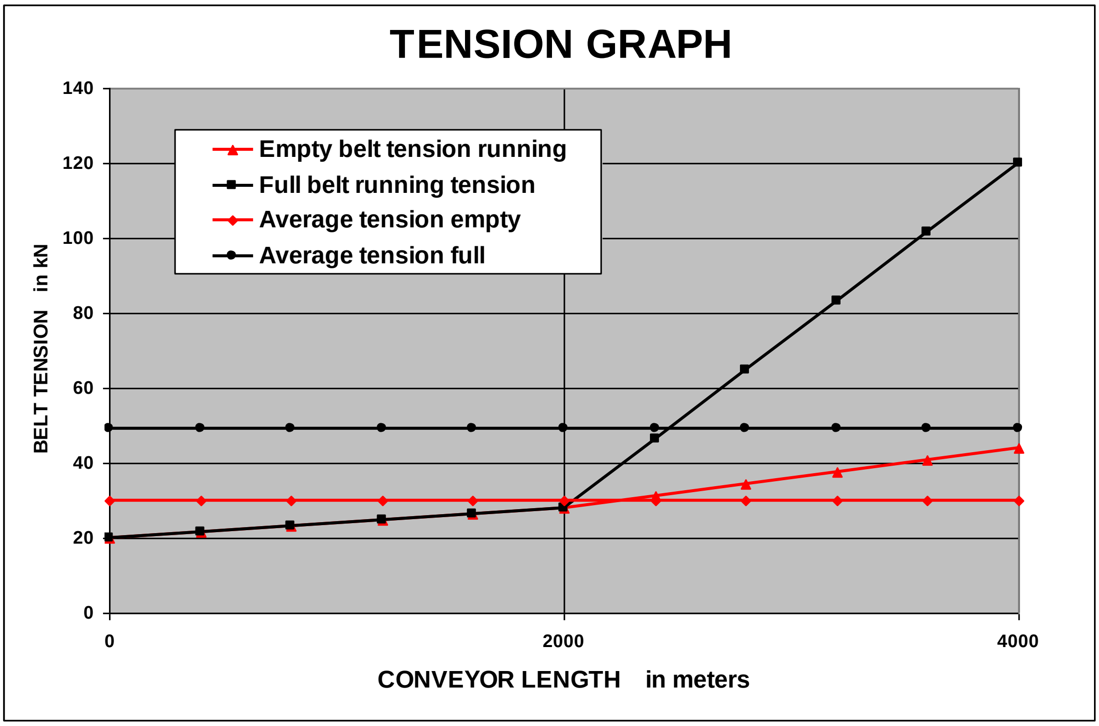


Figure 1 Diagram of a typical conveyor



Graph 2 tension graph of conveyor

The above graph represents the tensions on a hypothetical conveyor (see Table 3) that is 2000 metres long. From 0 to 2000 is the tension in the return strand from the head to the tail. From 2000 to 4000 is the tension in the troughing side from the tail to the head. Thus point 0 is the head pulley on the return side, point 2000 is the tail pulley and point 4000 is the head pulley on the troughing side.

The next step is to review the process required to calculate the average tension in the system. Quite simply, it is the area under the tension line averaged over the distance.

- **FOR THE EMPTY BELT RUNNING IT WILL BE:**

$$ATA_{return\_belt} = \frac{T2 + T_{tail}}{2} \times L_{centre\_distance} \quad \ldots\ldots 1$$

Where: ATA_{return_belt} = Average tension area of the return belt

$T2$ = Take-up tension value

T_{tail} = Tension at the tail

$L_{centre\_distance}$ = Conveyor pulley centre distance.

$$ATA_{trough\_belt} = \frac{T_{tail} + T_{head}}{2} \times L_{centre\_distance} \quad \text{...2}$$

Where: ATA_{return_belt} = Average tension area of the trough belt

T_{tail} = Tension at the tail

T_{head} = Tension at the head

$L_{centre\_distance}$ = Conveyor pulley centre distance.

Finally average tension in the conveyor system is:

$$AT_{conveyor\ system} = \frac{AT_{trough\_belt} + AT_{return\_belt}}{2 \times L_{centre\ distance}} \quad \text{...3}$$

Where: $AT_{conveyor\ system}$ = Average tension of the conveyor system

- **EMPTY BELT CALCULATION:**

$$ATA_{return\_belt} = \frac{T2 + T_{tail}}{2} \times L_{centre\_distance}$$

$$= \frac{20 + 28{,}1}{2} \times 2000 \text{ kNm}$$

$$= 48100 \text{ kNm}$$

$$ATA_{trough\_belt} = \frac{T_{tail} + T_{head}}{2} \times L_{centre\_distance}$$

$$= \frac{28{,}1 + 44{,}1}{2} \times 2000 \text{ kNm}$$

$$= 72200 \text{ kNm}$$

$$AT_{conveyor\ system} = \frac{AT_{trough\_belt} + AT_{return\_belt}}{2 \times L_{centre\ distance}}$$

$$= \frac{48\,100 + 72\,200}{2 \times 2\,000} \text{ kN}$$

$$= 30{,}075 \text{ kN}$$

- **FOR THE LOADED BELT RUNNING IT WILL BE:**

$$\mathbf{ATA}_{\mathbf{return\_belt}} = \frac{\mathbf{T2} + \mathbf{T}_{\mathbf{tail}}}{\mathbf{2}} \mathbf{x} \mathbf{L}_{\mathbf{centre\_distance}}$$

$$= \frac{\mathbf{20} + \mathbf{28{,}1}}{\mathbf{2}} \mathbf{x\ 2000}\ \text{kNm}$$

$$= \mathbf{48100}\,\text{kNm}$$

$$\mathbf{ATA}_{\mathbf{trough\_belt}} = \frac{\mathbf{T}_{\mathbf{tail}} + \mathbf{T}_{\mathbf{head}}}{\mathbf{2}} \mathbf{x} \mathbf{L}_{\mathbf{centre\_distance}}$$

$$= \frac{\mathbf{28{,}1} + \mathbf{119{,}9}}{\mathbf{2}} \mathbf{x\ 2000}\,\text{kNm}$$

$$= \mathbf{148000}\,\text{kNm}$$

$$\mathbf{AT}_{\mathbf{conveyor\ system}} = \frac{\mathbf{ATA}_{\mathbf{trough\_belt}} + \mathbf{ATA}_{\mathbf{return\_belt}}}{\mathbf{2\ x\ L}_{\mathbf{centre\ distance}}}$$

$$= \frac{\mathbf{48100} + \mathbf{148000}}{\mathbf{2\ x\ 2000}}\,\text{kN}$$

$$= \mathbf{49{,}025}\,\text{kN}$$

The easiest way to interpret these values is to look at it graphically. (See Graph 2). The horizontal lines are the average tensions with the lower one being the empty and the upper one the full belt condition. Note that the return belt tension is the same whether it is for the empty or full condition. The lower angle tension is the empty belt and the higher angled tension the loaded belt condition.

The next step is the exciting one. Review the average tensions for both empty and the loaded condition. Now note where the T2 tension value is. One must remember that this is an applied tension and has no relevance on the power requirements. Everything above the T2 value must be seen as resistances that need to be overcome in order to run the system. The logic that now jumps out is that the average of the effective tension is thus everything above the T2 tension line.

Advancing onto the next step, if the average tension is known for running the system full, surely if a start factor is applied to that the end result will be the average tension during the starting cycle.

Applying the aforesaid to our example:

$$\mathbf{Te}_{\mathbf{average\_running}} = \mathbf{T}_{\mathbf{average\_running}} - \mathbf{T2} \quad \ldots\ldots 4$$

$$= \mathbf{49{,}025} - \mathbf{20}\ \text{kN}$$

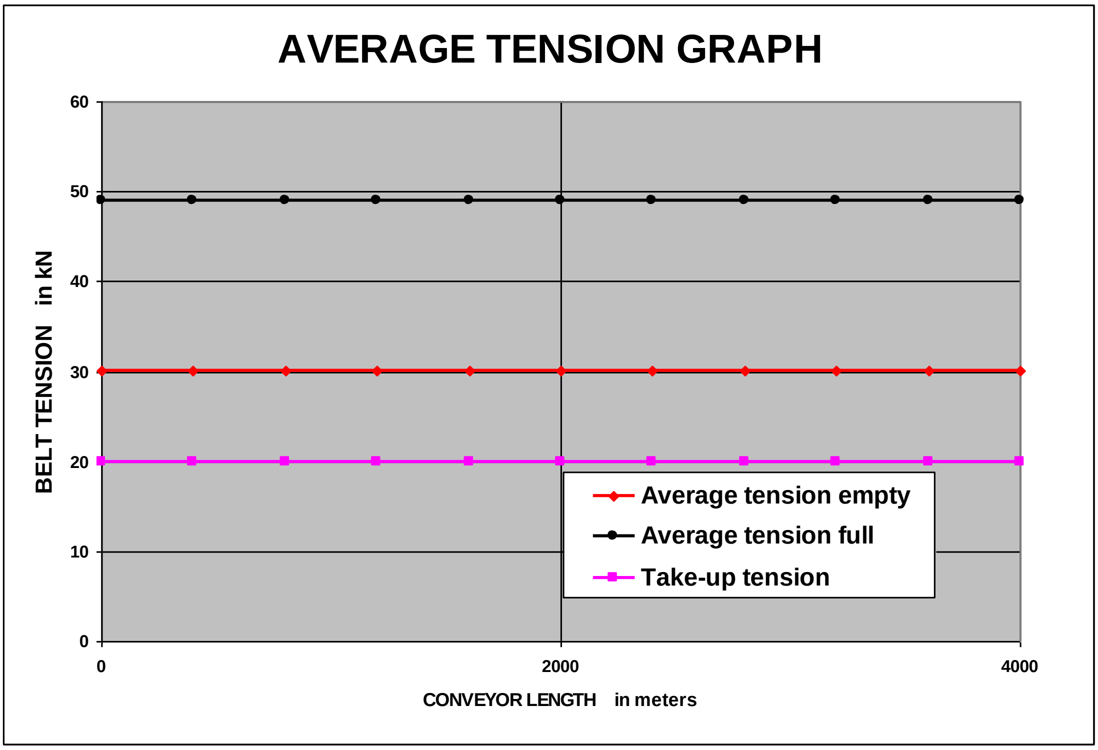
$$= \mathbf{29{,}025}\ \text{kN}$$

Calculate average tension during starting:

$$\mathbf{T}_{\mathbf{average\_starting}} = \mathbf{Te}_{\mathbf{average\_running}}\ \mathbf{x\ Start\ Factor} \quad \ldots\ldots 5$$

$$= \mathbf{29{,}025\ x\ 1{,}3}\ \text{kN}$$

$$= \mathbf{37{,}765}\ \text{kN}$$



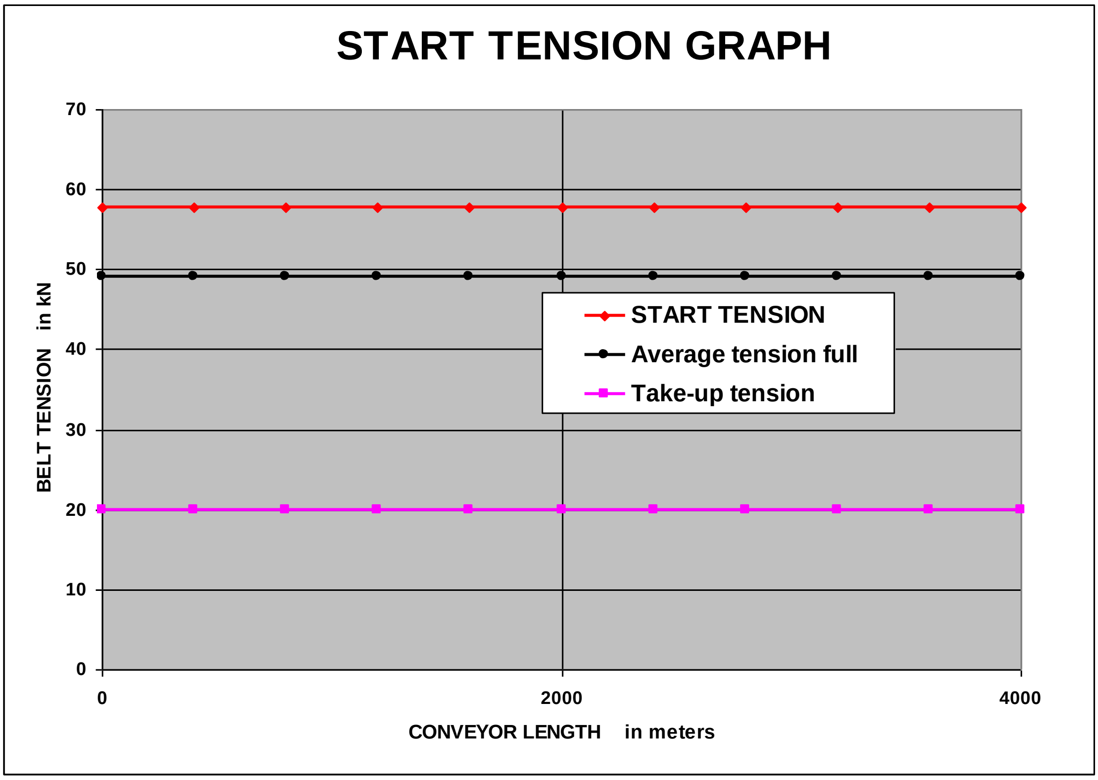
Graph 3 Average tension graph

Calculate required starting tension:

$$\mathbf{T}_{\mathbf{start}} = \mathbf{Te}_{\mathbf{average\_starting}} + \mathbf{T2} \quad \ldots\ldots 6$$

$$= \mathbf{37{,}765} + \mathbf{20}\ \text{kN}$$

$$= \mathbf{57{,}765}\ \text{kN}$$



Graph 4 Start tension graph

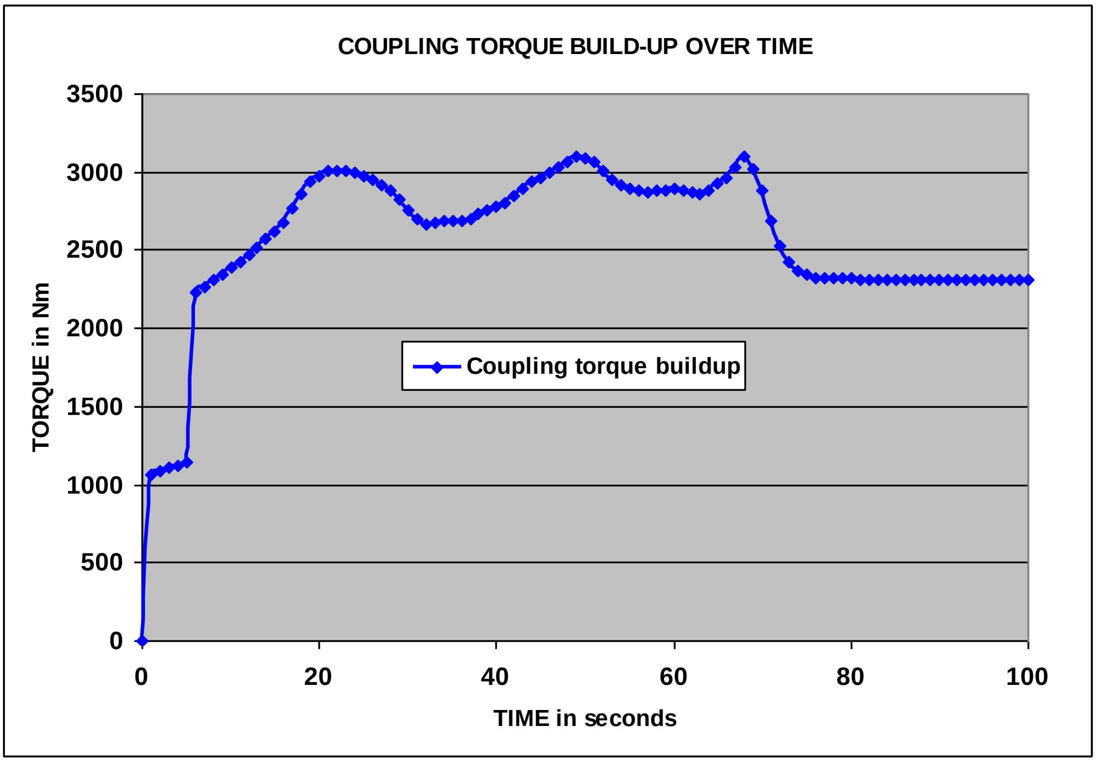
In addition to the start tension value, the above graphs show the average tension for the empty as well as the full belt. Note that the start tension value is higher than that of the average tension of the full belt condition. It is then impossible for a situation to develop where the average start tension value will be exceeded by any one of the load conditions from being completely empty and being fully loaded.

- **STARTING REQUIREMENTS**

In order to complete the cycle and as the secondary objective, one would need to review the rate at which the torque builds up for starting the conveyor and changing it from being in the stationary condition to the running condition. At this point reference is required to an earlier paper at Beltcon 7 on this subject. "**Refining conveyor specifications and operating procedures to cut running costs and downtime. Beltcon 7 1993;** authors A Surtees and S. Curry." The reference made to this paper is more for convenience should more detailed information be required as the process described in this paper is covered below.

In a nutshell, the approach is again simplistic and there is no reason why it should not be. The way to ensuring that the conveyor changes from the stationary state to the running state successfully every time is to make sure that the rate at which the starting torque builds up is always less than that of the speed curve as per the Funke line.

In order to demonstrate this a graph was developed using the same information as per our original example. The fluid coupling used as per our example has been assumed to have a typical starting torque factor of 1,3. Graphs 5, 6 and 7 show the typical torque curve of this coupling for the 240 kW application.



Graph 5 Torque build-up graph of the fluid couplings

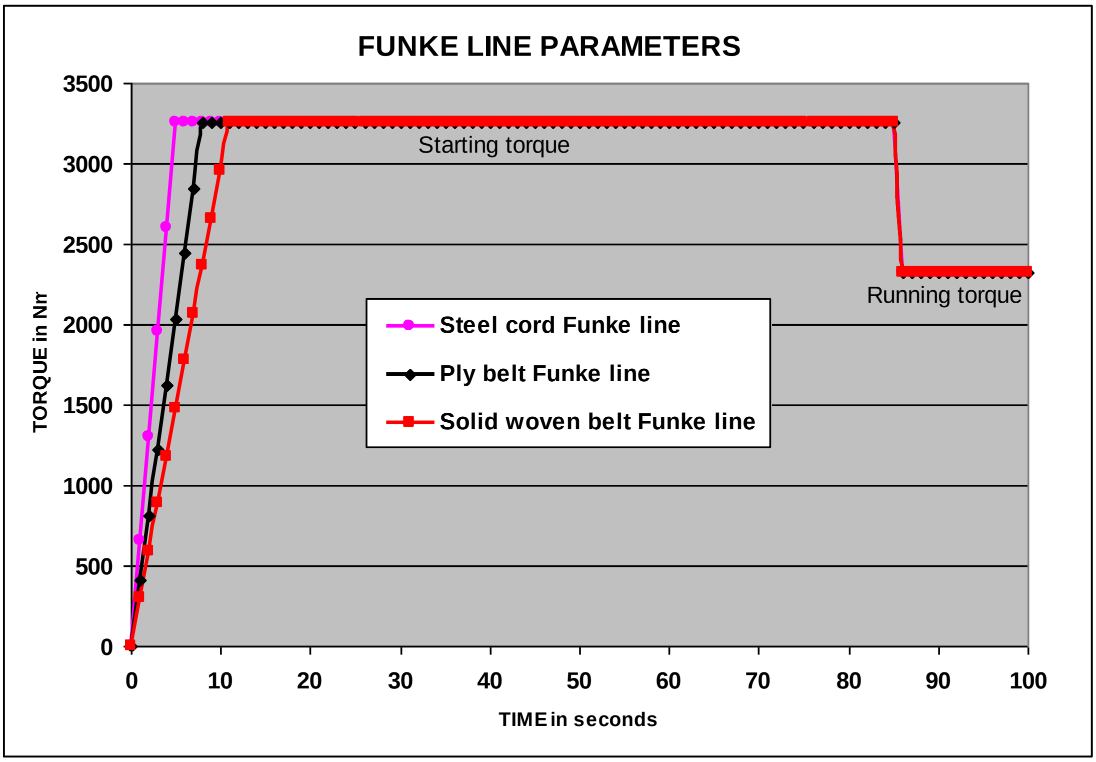
Graph 5 shows the combined torque build-up in the two drives operating with a 5 second delay between starting the primary and secondary drive units. The 5 second time delay is evident in the line shown just above the 1000 Nm torque value. As a point of interest, the time delay between starting drives can be varied within reason in an effort to try and further improve the starting characteristics.

At zero time the secondary drive is started and the torque in the coupling rapidly builds up to just over 1000 Nm due to the residual volume of oil in the working circuit of the fluid coupling. At this point the fluid from the centre chamber nozzles are entering the working circuit and the torque slowly increases accordingly with a relatively flat gradient.

When the primary drive is initiated after the pre-set 5 second delay, there is once again a rapid build up of torque due to the volume of oil now in the working circuit of the secondary drive.

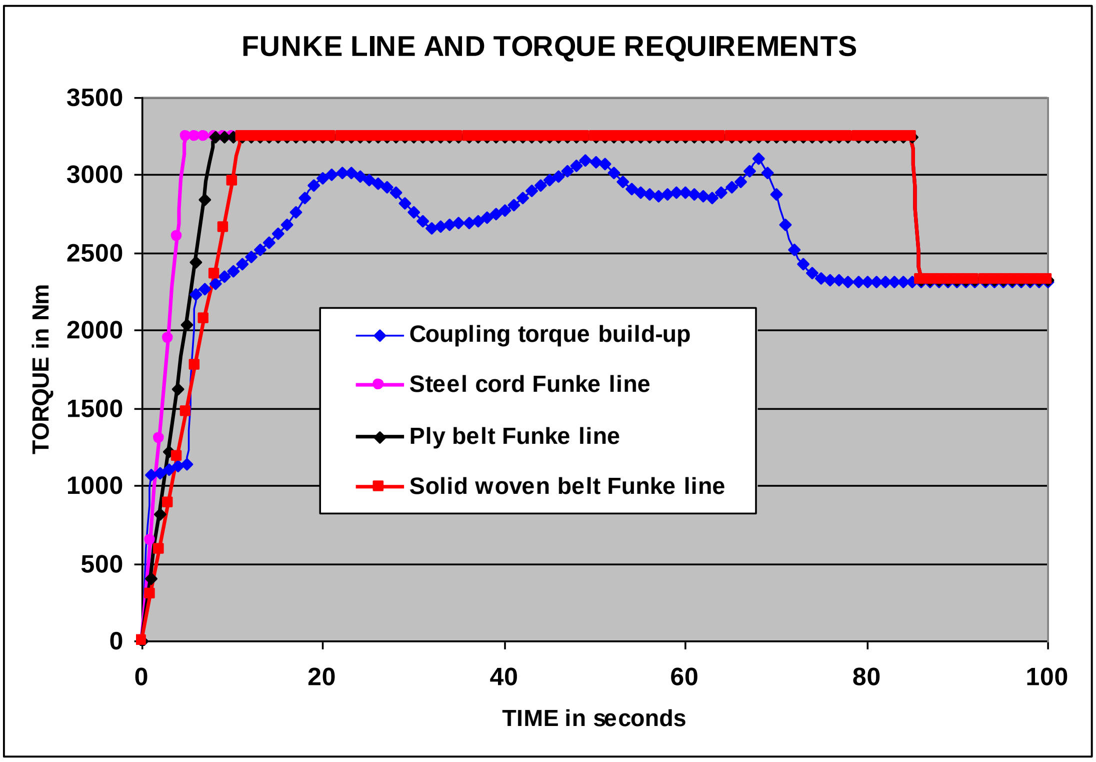
At the end of the rapid build up the combined torque increases to a maximum of about 1,4 times the applied power and will fluctuate accordingly to the specific characteristics of the fluid coupling until the conveyor belt is up to speed.

When the conveyor gets up to speed it will run at the constant torque requirement as can be seen by the straight on the right hand side of Graph 5 after about a 75 second starting time.



Graph 6 Funke line graph for all the belting types.

Graph 6 illustrates the Funke line start requirement for all the belting types. Note that the variance is only on the left as torque build-up takes place during the initial stage of starting.



Graph 7 Funke line and starting torque

Graph 7 shows the combined Funke line and the torque build-up during starting. The requirement is that the torque build-up must be below this line. From the graph it is evident that this coupling will be adequate for steelcord, marginal for ply and not suited for solid woven belting. Solid woven belting will require variable fill type couplings to be fitted.

4. CONCLUSIONS

The correct starting tensions can be readily determined for conveyor systems where tensioning is by means of slow speed automatic winches necessitating fixed tension starting typically in conveyors of length 500 m to 2000 m.

Using the Funke line approach, the suitability of the starting equipment can be confirmed.

5. RECOMMENDATIONS

Where users are experiencing problems with drive slippage, surging and excessive slack in the take up during starting similar type conveyors, consideration should be given to adopting the above approach for purposes of overcoming the problems.

If users are not comfortable with the calculating methodology, there are various consultants available in the industry that can assist with determining the correct starting tensions.

If users find that there are still problems after diligently confirming all the facts and figures, the best way forward will be to conduct a forensic investigation of the installation and obtain the performance signature of the installation for purposely quantifying the most efficient way forward.

6. REFERENCES

Surtees, A and Curry, S 1993 Refining conveyor specifications and operating procedures to cut running costs and downtime. Beltcon 7.

Belt conveyor for bulk materials. The Engineering conference of the Conveyor Equipment manufacturers association. USA

Recommended practice for trough belt conveyors. The Mechanical Handling Engineers Association. Britain

7. AUTHOR'S CV

The author has been directly involved in the conveyor industry for over 28 years. During this time he has been exposed to all facets of the conveyor industry ranging from mechanical design, manufacture, installation, commissioning, visual and forensic ore clearance audits and feasibility studies. The engineering of conveyor systems for both underground and surface applications are second nature to him. As current chairman of the Conveyor Manufacturers Association he is also active by serving on most of the SABS technical committees responsible for reviewing the national standards relative to all conveyor related issues.

Highlights of his career must be the four patents that he has been able to register as well as various firsts of conveyor installations conveyor systems like the first powered tripper drive in South Africa. Another milestone is the class 1250 solid woven dual booster conveyor designed for an underground application at an overall length of 7300 m.

Simon is currently employment with Sandvik Materials Handling as manager of engineering for underground materials handling systems.