Steel Cord Belt and Splice Construction
Modernizing Their Specifications, Improving Their Economics

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Summary

Belt conveyors constructed with steel cord tensile members are generally designed with a breaking strength rating that exceeds the operating load by 6.7 times. This multiple, or ratio, is often referred to as the Safety Factor (SF). This 6.7:1 SF has been chosen by belt manufacturers and industrial standards to represent the criterion for strength which engineers must follow during design development. This paper will demonstrate that their approach, developed over 30 years ago, is not practical today. It results in a significant economic penalty to the owner. Belt and splice construction materials and modern analytic procedures can provide safe operation using an SF ratio below 5:1 at breaking strength ratings from ST-1000 N/mm to above ST-6000 N/mm. Splice fatigue failure criteria and stress limits of the core rubber and cable are discussed. This method is used to resolve modern steel cord belt and splice design. The economic benefits can be substantial for new and replacement belt.

1. Introduction

This paper is an extension of the author's 1991 and 1993 papers, [1] and [2] respectively. Further research is being conducted on the viscoelastic power equation, the hyperelastic

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splice modeling methods, and fatigue mechanics of steel cable and rubber. These criteria and other notable influences provide the necessary refinements to guide the changes in belt and splice specifications and construction methods. These tools can support the mine owners' interest in ranking the performance of belts' rubber properties for its demand power (viscoelasticity), belt wear resistance (toughness), and true temporal capacity (splice design and belt construction). **All belts are not created equal.**

Field investigation, together with modern theory and laboratory studies confirm, firstly, that the empirical power equation [3] or [4] does not provide a reasonable level of accuracy [5], and, secondly, the belt's strength cannot be determined from elementary testing of cable breaking strength and rubber H-block static pullout forces [2]. These grey areas of understanding need a more accurate approach to fulfill the demands placed on the engineer for today's larger and more costly conveying systems.

The belt Safety Factor (SF) will be developed from basic principles. Decomposition of the SF into its fundamental elements leads to an understanding of how a safe and reliable method can be employed to quantify a realistic SF value. The decomposition is an expansion of the methods set forth in DIN 22101 [3].

Some owners, engineers, and manufacturers have equated the static (pull-out) strength capacity of the splice with its dynamic, fatigue or endurance strength, claiming they can achieve a splice strength equal to 100% of the belt breaking strength. This reasoning is highly inaccurate as will be shown. Fig. 1 demonstrates the variability of the rubber's stress intensity using FEM techniques. The stress is not homogeneous as some believe.

Fig. 1: Finite Element Model of splice 3-step pattern (213-) illustrating maximum stress intensity zones in rubber. New splice designs reduce critical stresses yielding greater strength and reduced cost
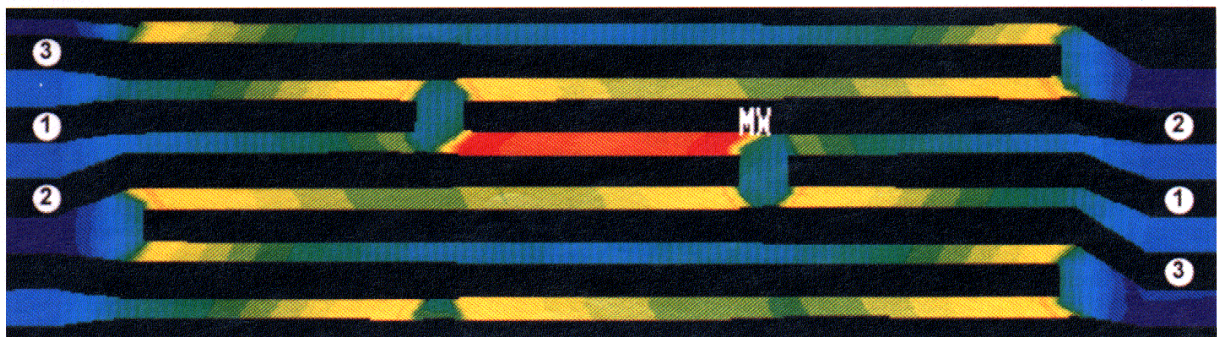
2. Dollars and Sense

New and replacement belt, designed with standards appropriate for the application, can make significant profit from an engineered reduction in the 6.7:1 Safety Factor. Direct savings come from the reduction in belt strength and belt weight affecting motor size, power demand, reducer selection, number and complexity of splices, pulley assembly sizes, idler life, structural steel supports, civil works grading allowances, etc. The belt can be 25% or more of the total conveyor investment. The difference in cost can result in millions of dollars in savings. The greatest savings are achieved with a relatively horizontal (slight undulation) belt profile. Conveyor Dynamics, Inc. (CDI) assisted in the design of the Channar 20 km overland conveyor in Australia [5], where the *SF* = 5.0:1, but DIN 22101 was enforced by an engineering audit (Case 2 below). A relative belt cost savings table shows a significant difference in conventional standards versus the recommended approach using Case 3 as the basis.

Case	Belt SF	Remarks	Cost Penalty
1	6.7:1	Designed per DIN 22101	39%
2	5.0:1	Designed per DIN 22101	23%
3	4.5:1	Recommended Design	0%

Note:

a) Case 1 is designed with conventional friction factors, and conventional published splice methods.

b) Case 2 is designed with a slight reduction in conventional friction factors noted for superior installation alignment and maintenance – Channar Design.

c) Case 3 is designed to new power equation methods, and a belt specification and construction formulation controlled by the splicing system – Channar and other measurements, since 1989, verify the potential.

3. Manufacturers Recommendation for Safety Factors in Steel Cord Belts

Some of the leading steel cord belt manufacturers were polled for their assessment on support of the reduction in the *SF*. Their comments are summarized here:

3.1 Bridgestone Corporation

Bridgestone Corporation completed a detailed investigation of the Belt Safety Factor in 1982. A finite element model was developed to study the non-linear rubber strain and fatigue behavior. Extensive testing was made on the fatigue performance of the belt's steel cords. These studies were produced in response to an inquiry for an ST-7000 N/mm class belt. Our investigation showed that this class of belt could be constructed with a Belt Safety Factor of 5.0:1 instead of the commonly used 7.0:1. Bridgestone has in service low Safety Factor belt which has been in operation for more than 10 years. Regular monitoring of its performance has provided understanding that the practice is sound.

We continue today, through further research and testing, to advocate improved Safety Factors to keep pace with advancements being developed in materials and engineering methods. Dynamic fatigue testing of the belt and its splice pattern as defined by DIN 22110 are also a necessity when recommending new classes of belt construction [6]. Of course, we must bear in mind any reduction in the so called Safety Factor must also be accomplished with full understanding of all engineering issues and design standards which must apply.

The Safety Factor is dependent on many elements outside the control of the manufacturer. When the owner wishes a significant cost savings and is willing to participate in proper operation and maintenance, then greater benefits can be achieved. A Safety Factor closer to 4.0:1 may be offered.

The conveyor belts economics can have a large impact on the viability of mining projects. To these ends Bridgestone is providing its full support redefining the criteria and standards that promote a more cost-effective, power-efficient, and safer belt for the mining industry.

3.2 ContiTech Transportbandsysteme GmbH

The Safety Factors given in the old DIN standard DIN 22101 of Feb. 1942 were calculated with the maximum belt tension T1 and the breaking strength of the full belt width. This "rough method" resulted in a 10:1 or higher breaking to operating strength ratio. It resulted in an ultra-safe recommendation. This method of belt selection can even be found today mainly on the "low end" tension (fabric carcass) applications.

The Safety Factors have been reduced with the introduction of high strength EP-carcasses, steel cord belts, and improved methods of calculating the actual stresses on a conveyor belt. This is possible due to the understanding of better belt material construction properties and methods of calculating the maximum and steady-state belt tensions. These forces are specified for a maximum material loading in regular operation. This later development is a departure from specifying belt strength based on its static capacity. Instead now the dynamic strength and three other major operating conditions noted in DIN 22101 Feb. 1982 are common practice. The lowest Safety Factor named here is 4.8:1.

This way of belt selection, which is generally practiced today, makes use of more knowledge of the belt construction and better calculation methods of the belt tensions. It allows for a more accurate and therefore more economical and safer selection of the belt. Greater savings potential is still to come to the "high end" application.

The conveyor is a dynamic thing, nothing is static in starting, stopping and steady running. In the early 1980s, at the University of Hannover, a dynamic test method for conveyor belt splices was developed which allows now an evaluation of the belt and its splices with regard to the time strength behavior. Although this method has already been introduced in the DIN-standard DIN 22110 (Part 3, Sept. 1993) [6], up to now it has only been used by a few belt conveyor manufacturers, engineers, and users.

Knowledge of belt dynamic properties allows the engineer not only to develop the belt and the splice for better performance, but also to use a dynamic Safety Factor for the selection of belt and splice design. Today, this dynamic Safety Factor (splice dynamic efficiency) may be specified at a ratio of 2:1 or less. This results in an equivalent 50% splice dynamic efficiency. In the future, it will be necessary to have more information about the actual strain history on the belt and a corresponding collective model for its operation over the required service life.

3.3 The Goodyear Tire & Rubber Company

The definition of a proper Safety Factor for steel cord belts has been discussed among belt manufacturers, engineering firms, conveyor designers, and customers for years. Typically a 6.67 Safety Factor is offered for general practice and 8.0 for severe or abusive service. However with the advent of more sophisticated mathematical and computer analysis there is a trend to-

ward reduction in Safety Factor with "properly" engineered systems.

Perhaps the greatest difficulty in defining the Safety Factor is the acceptance of a suitable reference criteria, some of which can be listed as follows:

a. Belt ultimate strength.

b. Splice strength through static shear analysis.

c. Splice strength generated on small scale cyclic laboratory test equipment to determine rubber fatigue curves at tensions 2-3 times normal operation.

d. Splice strength determined by large scale two pulley dynamic test equipment operating at tensions 2-4 times normal operation.

e. Splice strength determined by finite element analysis which combines laboratory data with computer simulation of static shear loading.

In truth, all of the above have merit but none should be considered alone as the "true" Safety Factor. Each technique has benefits and provides information that can be used by the belt engineer in designing the correct splice for the specific application.

The Safety Factor can be reduced using theoretical studies, when the total belt system has been analyzed for all transient and loading conditions. This reduction in Safety Factor can offer the end user considerable savings in capital cost from the belt and other components.

However, Goodyear has been reluctant to recommend a reduction in Safety Factor beyond 6.67. In many cases, belt systems are designed for 10-15 years of operating life before requiring replacement. When the original operating tensions are calculated, the ideal friction and loading are inputted. Practical experience has shown that maintenance conditions can deteriorate and that mine tonnage requirements can be increased beyond original expectations.

Also it is common for accidents to occur such that a large number of cords in the body of the belt are broken or damaged. A reduced Safety Factor, based totally on splice strength, makes no provisions for these conditions and could result in lower ton-

Fig. 2: One and two step splice arrangements with dimensional variables – section through horizontal axis

a. Single Step Splice

b. Two Step Splice

nage rates until replacement belt is acquired. With 6.67 and higher Safety Factor it is not uncommon to have up to 10% of the cords damaged or broken without consideration to reduced tonnages.

Although a reduction in belt Safety Factor below 6.0 is possible and has been supplied by Goodyear, it should only be considered after careful analysis of future mine maintenance conditions, possible damage to the belt through operations, and risk analysis of cost due to mine downtime.

Author's Note:

The dynamic *SF* for hoisting ropes begins at 5:1 [7] [8]. These ropes are not impregnated with rubber and have a sheave to rope diameter ratio usually below 50:1. The belt high tension pulley diameter to cord diameter ratio is usually at 100:1 or larger. The most significant factor is that the belt cover protects the belt's steel cord, whereas the hoist rope bends around bare steel sheaves.

4. Splice Structural Definition

Splice patterns shown in Fig. 2 are defined by the number of steps and step arrangement. They are made up of seven fundamental dimensions:

d   effective cable diameter given by cable manufacturer

p   cable pitch, the distance between cable centers in belt

g   rubber gap, the closest distance between cable diameters in splice

e   distance between cable ends

b   cable bending zone transition between splice end and its steps

S   step length, proportion of each cable that ends in splice in relation to splice length excluding bend zones

L   splice length, total length of cables passing including *e*, *b*, and *s* (bend zones are excluded for this paper).

The numbered black zones illustrate the rubber panels in shear from opposing cables. We refer to this as the active shear stress zone. Historically, this method has been used by manufacturers to calculate the splice strength (i.e. more panels and their total length for a given step pattern equate to greater strength). This is not true for more than the single step splice. The non-black zones, in the two step, also contribute.

The white unmarked areas are called the passive shear stress zones, where the cables are pulling together in the same direction. They also transmit shear forces due to differential elongation between cables. Comparing Fig. 1 to Fig. 14 illustrates that the white areas can transmit a significant force and cannot be neglected in the splice analysis. Fig. 9 illustrates typical rubber loading in each of the shear panels between cables. This also shows significant response in the passive shear panels.

5. Safety Factor Definition

The term Safety Factor, used by belt manufacturers and industrial standards, does not imply any value on the margin of safety available beyond the design operating load. In its simplest form, the value of the Safety Factor (*SF*) is equal to the total belt cable breaking strength (not splice), divided by the belt design operating load under ideal conditions.

$$SF = \text{static break strength} / \text{design load} \qquad (1)$$
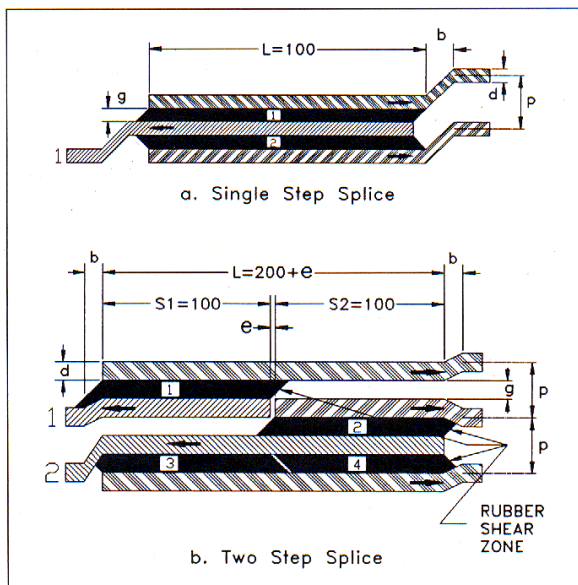
The belt static strength or ultimate strength is not an appropriate design criterion for dynamic operation. Both the cable and rubber undergo structural damage when subjected to repeated cyclic steady-state and dynamic transient loads. The rate of structural damage is defined by each material's fatigue or endurance strength relative to the number of load cycles [9] [10] [11] [12] [13] [14]. The belt's steel cable infinite life cycles can only be guaranteed when the peak cyclic load is kept below 25% of the cable's breaking strength. Rubber continues to degrade with cyclic loading, as the polymer's molecular chains breakdown (scission) from repeated strain even under relatively light forces. The life cycles are exponentially dependent on the applied force (stress) as shown in Fig. 3 and its phenomenological equation:

$$f \text{ (life cycles)} = \alpha \cdot e^{\chi} \qquad (2)$$

where $\chi = (\beta \cdot \text{force} + \delta)^{\eta}$, and α, β, δ and η are functional constants depending on rubber compound, cable construction, and splice pattern, including axial and bending stress history. Delta (δ) equals infinite life parameter of rubber or steel cord.

The fatigue decay rate and endurance curve stress magnitude can be significantly improved with special rubber compounding and additives. Belt manufacturers have developed special rubber compounds which yield superior fatigue and adhesion properties while also resisting environmental attack.

The Safety Factor can be decomposed into five major independent sub-classifications, four of which are shown in Fig. 3. Decomposition provides assessment of the individual contributions of each factor.

1. Splice Fatigue (Rubber & Steel Materials, Pattern; Load)
2. Elongation (Bending, Flexure, Transitions; Curves)
3. Degradation (Damage, Errors and Omissions)
4. Dynamic Loading (Starting and Stopping)
5. Steady-State Loading (Running).

Each of the sub-classifications also has many factors contributing to their allowable stress or strain ranges. In addition, the individual sub-class items have tolerances on their stress ranges which must be rationalized.

5.1 Splice Fatigue Allowance

The splice strength can vary with its materials and methods of construction. Some of the main features include:

a. Rubber and steel properties (special compounds which resist fatigue, special cable designs) Fig. 4

b. Rubber core gap (g) – increasing g reduces rubber stress and increases steel cord stress per Fig. 5. Normalized refers to the gap dimensionless property.

c. Splice step number, 1, 2, 3; 4 (high steps are less efficient, due to the increase in stress concentration in their rubber and steel)

d. Splice pattern – step sequences impose different stresses on rubber and cables, as shown in Fig. 14 and noted in 6.1c [2] [12].

e. Splice length – 95% of the strength can be achieved from 50% of the beneficial length. Usually it is larger than belt manufacturers' recommendations, Fig. 13.

5.1.1 Splice Core Rubber Gap

The splice core rubber and its gap specifications are probably the single most important feature of the splice. It is the hardest dimension to control with any accuracy, and has the most pro-

found effect on the usable belt strength when not sized or constructed correctly.

Manufacturers and standards have published recommendations for the core rubber gap. Fig. 6 illustrates the core rubber gap of three major manufacturers, the standard DIN 22131 [16], and their mean over the range of steel cord ST-ratings. Regardless of the strength rating, the value of g equals about 2.5 mm. H-block pullout testing demonstrates that significant improvement is realized by equating the core rubber gap to the cable diameter as shown in Fig. 7. Using CDI's FEM pullout values
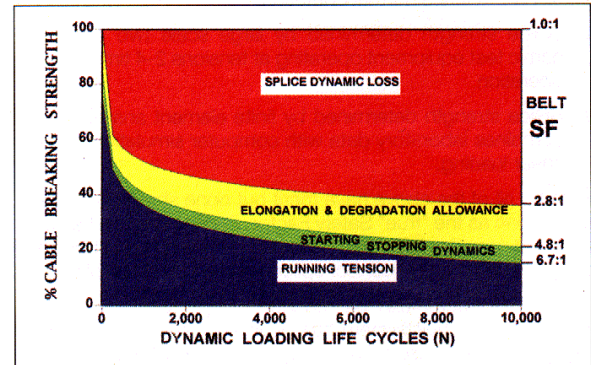

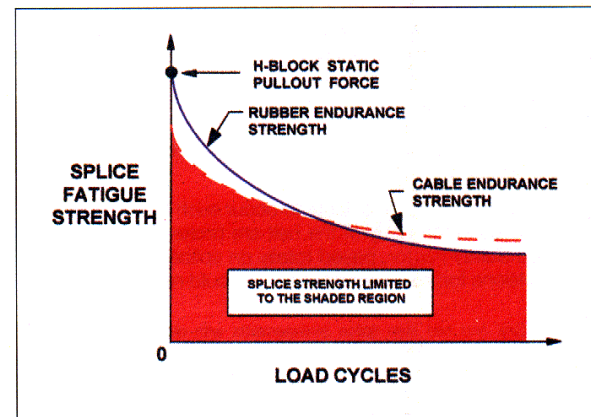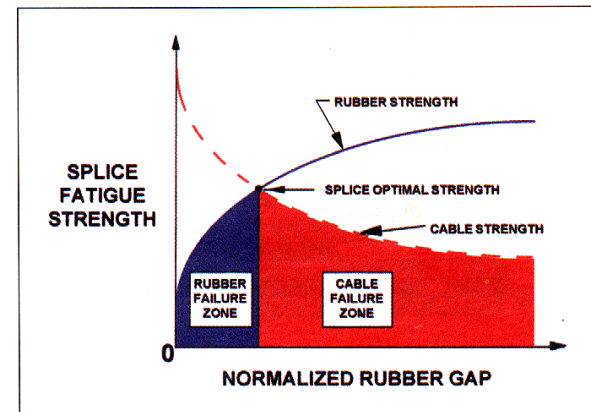Fig. 3: Splice endurance and belt safety factor curve

Fig. 4: Splice fatigue strength vs. load cycles on rubber and steel

Fig. 5: Splice strength vs. optimized step length (normalized length is dimensionless)

which are dependent on the *g/d* ratio in Fig. 7, the pullout strength of the splice is plotted in Fig. 8. Fig. 8 clearly demonstrates that these practices seriously underrate the splice potential and reduce the belt's economy . We recommend the optimization concept proposed in Fig. 5.

Core rubber endurance properties cannot be inferred from the H-block pullout test results [14]. Static pullout testing can only provide an estimate of cable adhesion.

A number of different FEM stress plots, Figs. 9-11, are provided to show the sensitive regions and the magnitudes of change. The color gradients are shaded in 19 hues illustrating the maximum to minimum stress, or from a positive to negative extreme. The stress plots were developed from the 3-step pattern shown in Fig. 14.

The core rubber is loaded in axial shear, transverse shear (torsion), and in tension. Fig. 1 illustrates the rubber's maximum
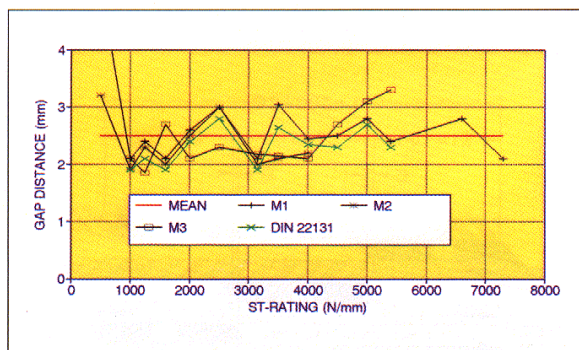
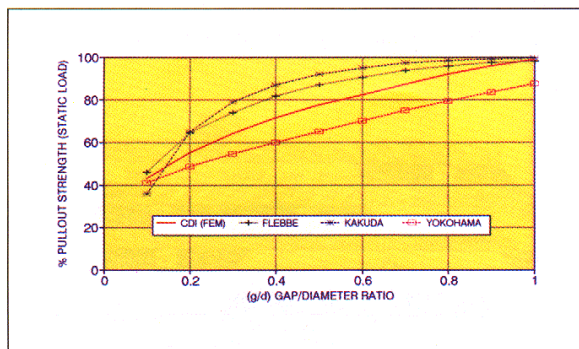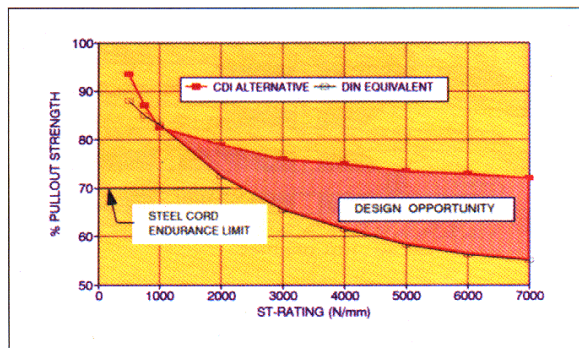Fig. 6:   Core rubber gap distance vs. published ST-ratings

Fig. 7:   H-block pullout force vs. rubber gap to diameter ratio (*g/d*)

Fig. 8:   Pullout force per Fig. 7 vs. published ST-ratings and alternattive

stress intensity for the typical 3-step, 213- pattern. Figs. 9–11 illustrate the FEM results on the magnitude of axial shear stress, torsional shear stress, and tensile stress. Torsional stress represents 10-15% of the axial shear. The torsional stress comes from the cables' rotation which is coupled to its axial extension through the helical arrangement of the wire groups in the cable, and through twisting when bent over pulleys.

Accuracy of the FEM analytic techniques have been verified by testing of actual splice designs on the Hannover University machine [6] and by laboratory dynamic testing. CDI designed a special jig to test the fatigue characteristics of rubber. Testing, with the jig, was carried out by a leading belt manufacturer. The results equal the hundreds of dynamic tests conducted at Hannover as reported in the thesis of H. VAN DER WROGE [12]. He calculated that when the belt achieved 10,000 load cycles, with all splice patterns and manufacturers considered, the shear stress equaled 2.2 mPa ± 15%. The CDI test jig was used on one rubber compound. Twenty- four tests were conducted, at differing core gaps, and a range of forces that produced one fatigue failure curve for the rubber. The number of load cycles ranged from less than 1,000 to more than 30,000 repetitions. The shear stress curve, at 10,000 load cycles, equaled 2.19 mPa ±10%. The rubber fatigue failure curves of VAN DER WROGE, CDI, and HAGER [14] obey Eq. 2.

5.1.2 Splice Step Length

Forces are transmitted between cables by a shear panel which, in simple terms, is described by a width, height, and length. The core rubber gap (*g*) approximates the width, the cable diameter (*d*), the height, and the step dimension (*s*), the length.

The step length selection depends on cable diameter, cable construction, splice step sequence, rubber properties, and proprietary practices of some manufacturers [15].

Three belt strengths were selected from the DIN Standards 22129 and 22131 to illustrate how this standard has specified the shear panel. The dimensional comparisons are made in pro-
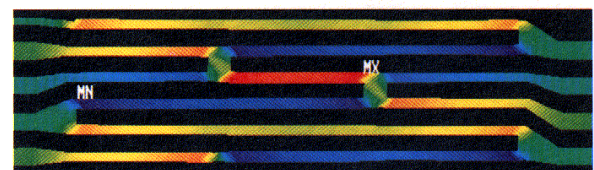

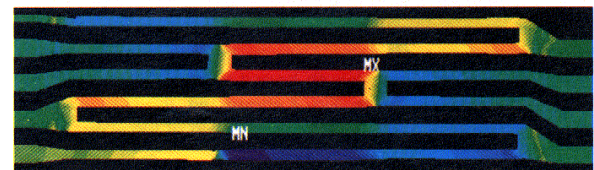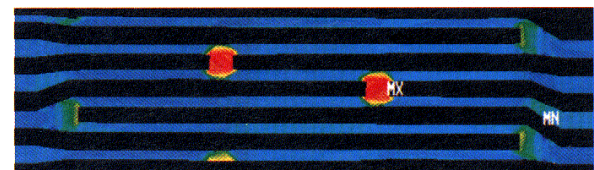Fig. 9:   FEM axial shear stress gradient in 3-step splice pattern (213-)

Fig. 10:   FEM torsional shear stress gradient in 3-step splice pattern (213-)

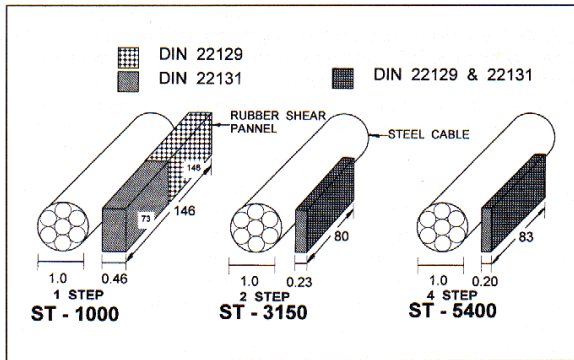Fig. 11:   FEM tensile stress gradient in 3-step splice pattern (213-)

Fig. 12: Splice step, cable and core rubber sizes proportional to their respective diameters
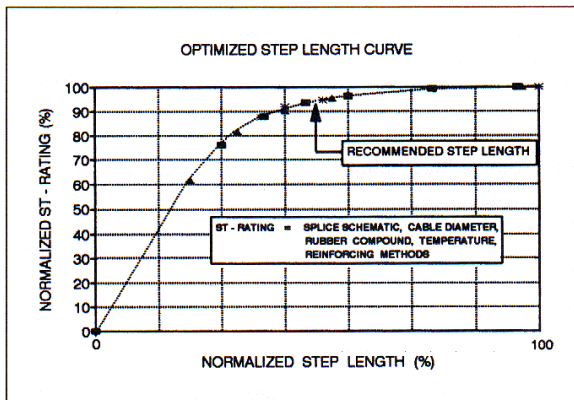
Splice Pattern	Max. Rubber Shear $\sigma_{max}/\sigma_{nom}$	Max. Cable Force F_{max}/F_{nom}
123-	1.43	1.17
132-	1.25	1.27
213-	1.22	1.25

Note: These results are for one cable diameter and its construction, as recommended by a belt manufacturer without regard to optimization.

There are other 3-step patterns that provide superior benefits. Proprietary patterns, cable designs, core gap arrangements, reinforcing techniques, and rubber compounds all reduce the maximum to nominal load ratios closer to 1:1.

Fig. 13: Optimum splice strength vs. core rubber gap (normalized gap is dimensionless)

Fig. 14: Standard 3-step patterns. Three alternatives and their stresses.

a. 3-Step 123 DIN Standard Pattern with Peak Stresses

b. 3-step 132 Pattern with Peak Stresses

c. 3-Step 213 Pattern with Peak Stresses

portion to their respective diameters as shown in Fig. 12. A greater gap (g) and greater step length (s) each reduce the rubber's shear stress. When comparing the three shear panels in proportion to their cable diameters, the higher strength belts have small gaps, lengths and shear panels to carry the force. Their optimization is suspect.

Fig. 13 illustrates the general form of the CDI optimized step length, where the step length is defined as the dimension of the critical cyclic shear stress zone. 95% of the step length strength is achieved in 50% of the optimum length. This is larger than is normally recommended.

Some manufacturers continue to cite the shear load capacity, splice pattern, and step length based upon H-block static experimental measurements. Fig. 4 shows that the H-block static pullout strength is clearly not representative of the splice endurance strength.
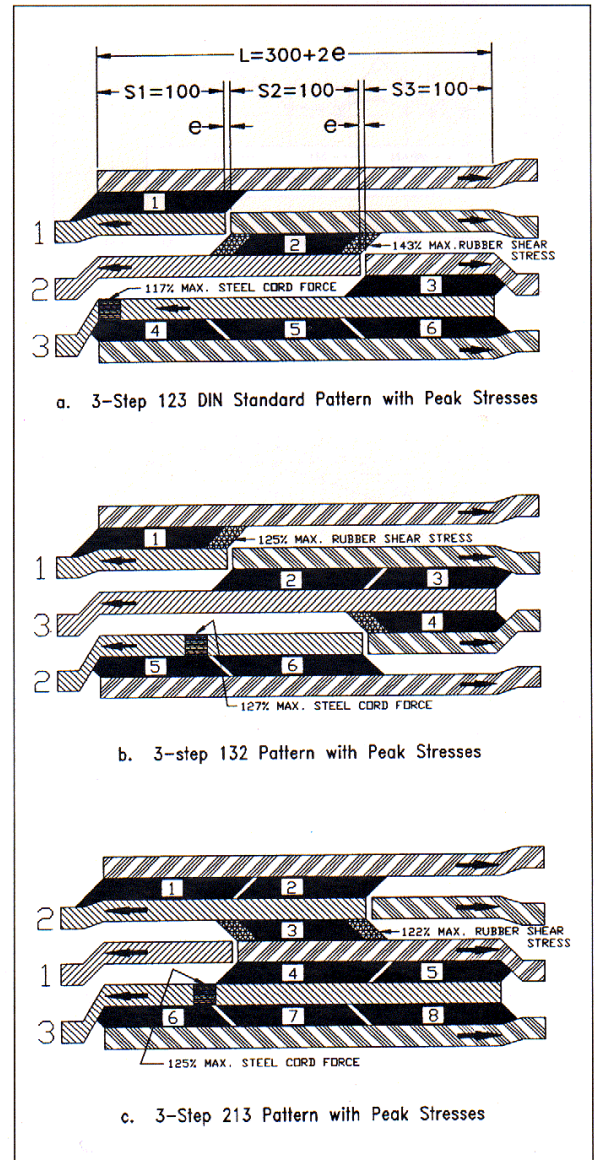
Fig. 14 illustrates the 3-step configuration and step length formulations for three typical, frequently recommended patterns. The pattern sequence numbers, 1, 2, 3, denote the respective order and length each cable is embedded in the splice proportional to the maximum step length for one repeating pattern. The 123- step sequence is the DIN 22131 recommendation for surface conveying. The 132- pattern is the DIN 22129 pattern for underground service [17]. The 213- pattern is recognized by some belt manufacturers as superior to the other two patterns. Comparing these three patterns, using FEM, we find the peak rubber and cable loads are:

5.2   Degradation and Elongation Endurance Forces

Degradation and elongation forces are additive to the running force and set the minimum endurance limit of splice strength. They are rarely quantified by the engineer.

Elongation refers to a class of forces or stresses which produce additional strain or elongation, such as: idler transition shape change to high tension head pulley; convex vertical belt curve edge stresses in the high tension region; bending of the belt over pulleys, causing added torsional strain on the rubber from cable twist; turnovers, belt alignment, etc. They can be calculated. DIN 22101 allows 100% of the running tension for the many possible forces that are omitted from standard calculation methods.

The significant values are:	%Running Tension
1. Idler transition (FEM studies)	≤15%
2. Belt alignment (using CEMA and DIN 5% allowance)	≤15%
3. Vertical curves (not generally applicable)	≤10%
4. Bending over pulleys	≤10%
Total	**≤50%.**

Degradation allowance accounts for general damage caused by:

- splice construction errors
- belt age
- rock impact
- transition idler alignment errors
- pulley alignment errors
- pulley diameter shape errors
- cover wear transverse variations
- drive load sharing anomalies
- surface buildup on pulley and belt
- proximity of pulleys to each other
- fixed take-up & high take-up travel hysteresis
- pulley lagging shape errors
- general cable breakage (rock entrapment, etc.).

The present standard allows for elongation, but does not discuss degradation. It is implied without detail. Elongation and degradation strength factors exceed 100% of the design running force. Degradation alone exceeds 50%. The operator can make significant contribution to lowering his capital cost by practicing a good maintenance policy.

Field constructed splices, we believe, contribute at least 25% of this allowance. Our inspection of many splice X-ray patterns throughout the world, leads us to believe that only a few vulcanizing contractors and plant crews have the technical knowledge to properly construct a splice. Many errors are made without their knowledge. Often the construction errors reduce the effective strength by half, causing splice failures to occur within one or two months. In engineering terms, the splice construction errors can reduce the belt strength by a factor equal to, or exceeding, the belt material transport design load. They can be avoided with proper training in the splice functions and making certain the splice crew have knowledge of the calibration and maintenance of the vulcanizing machine.

We recommend the splice construction degradation allowance be increased to 60% of the running tension unless special methods are used to control fabrication. This loss is made up by the reduction in the dynamic allowance section.

No benefit in splice technology can be achieved unless the splicing contractor is aware of the importance of his function and that he can meet the specifications of proper splice procedures.

Figs. 15 and 16 show some good and bad techniques. These figures are X-ray patterns taken on conveyors of significant capital.

5.3   Dynamic Analysis (Starting & Stopping)

DIN 22101 calls for starting and stopping strength allowance equal to 40% of the running force (favorable operation).

$$\% \text{ Start} = \left[\frac{SF\,(\text{Starting})^{-1}}{SF\,(\text{Running})^{-1}} - 1 \right] \times 100$$

$$= \left[\frac{0.209}{0.149} - 1 \right] \times 100 \ (\text{Ref. Fig. 3})$$

$$= 40\% \tag{4}$$

CDI has different criteria for dynamic forces which are beyond the scope of this paper. When high momentary loads are applied, and are frequently repeated, then special endurance or material yielding stress limits must be evaluated.

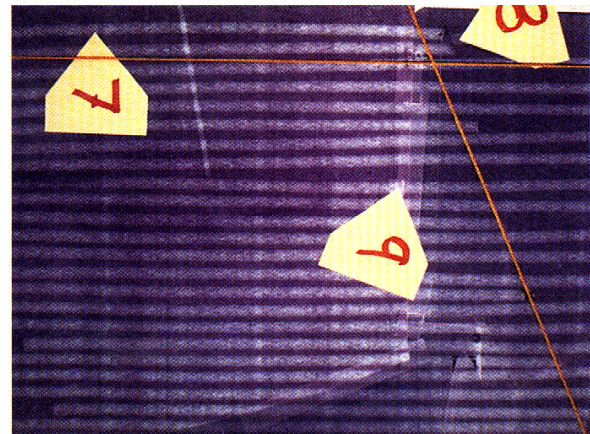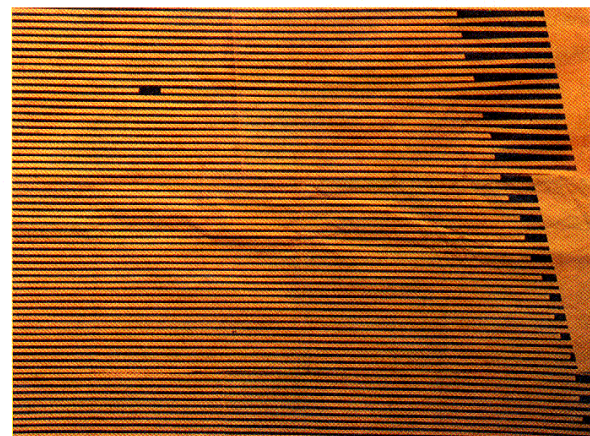A simple analogy shows the effect of momentary starting.

Fig. 15:   X-ray of bad splice technique. One cable carries no load (8), and small gaps (8, et al.), large gaps (7 & 9) and poor cable alignment is evident.

Fig. 16:   X-ray of good splice technique

Assume the following:

1. 40% start overload per DIN 22101
2. 1 minute per start per 1,000 m transport distance
3. 10 starts per day
4. 1,440 minutes per day operation
5. Belt speed 5 m/s
6. Damage is simple exponential function.

Starting influence on SF (dynamic):

$$SF \text{ (dynamic)} = \exp\left\{-\frac{No}{Ax}\right\}, \text{ where}$$

$$No. = 10,000 \text{ load cycles and } SF \text{ values}$$

$$Ax = No\left[\frac{-1}{\ln(\text{Run})} + \frac{-\gamma}{\ln(\text{Start})}\right]$$

$$start = 1.40 \times run = (1.40)(0.2985) = 0.4179$$

γ = ratio $start$ to run cycles per day

$$= \frac{10}{216} = 0.0463$$

SF(dynamic) = 0.321 with respect to run

$\qquad$ = 15% with respect to running $SF = 6.7 : 1$

$\qquad$ = $(1.15 \times 0.1492)^{-1} = (0.1716)^{-1} = 5.8$

SF (dynamic) = 5.8 :1, not 4.8 :1 as in DIN 22101.

Therefore, the dynamic forces do not contribute greatly to the overall endurance strength allowance for most conveyor systems.

Today, CDI provides a 15% strength allowance over the running force for dynamic forces imposed on the splice, not the DIN 22101 40%.

5.4 Power Equation

This section is included to show that significant errors can be made in the assessment of belt tensions based on standard power equations. This error becomes exaggerated when the belt strength is specified. Using the rule $SF = 6.7:1$, the cost increases dramatically.

The conveyor's main rolling resistance is produced by four major and three minor factors:

Major:

1. Idler indention into the belt cover rubber
2. Belt flexure over the idler trough and between idlers
3. Material agitation or trampling together with belt flexure
4. Idler bearing and seal drag.

Minor:

5. Drive assembly efficiency losses
6. Flexure of the belt over pulleys
7. Material loading acceleration turbulence and skirt drag.

Idler indention (deformation) accounts for 60-80% of these losses depending on the rubber's viscoelastic properties. Viscoelasticity is the term which defines the hysteretic loss that occurs in the rubber during deformation.
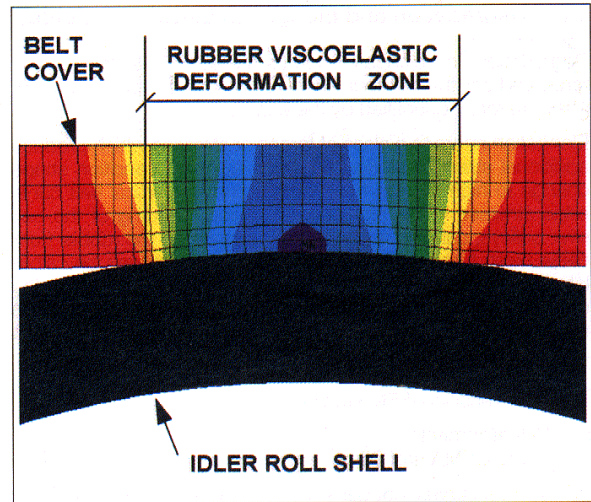

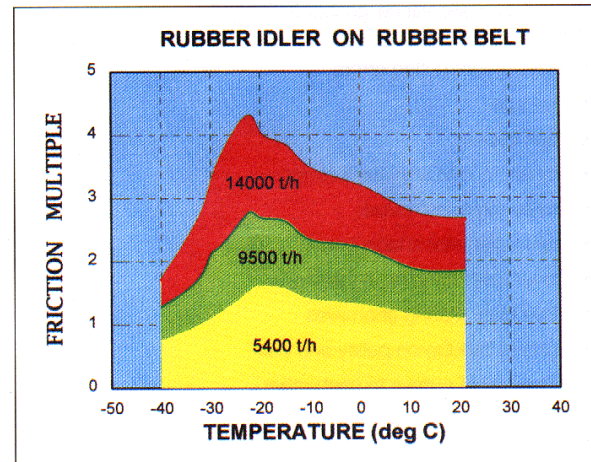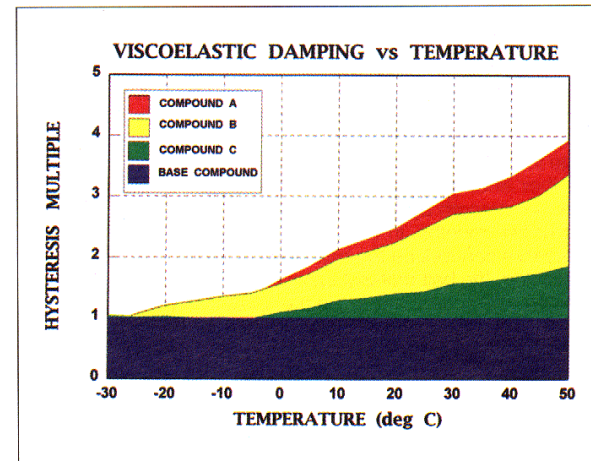Fig. 17: Deformation of rubber by idler indentation (static case)

Fig. 18: Rubber hysteresis multiple vs. temperature at three tonnages – rubber belt on rubber covered idlers

Fig. 19: Rubber hysteresis vs. temperature for four compounds

ISO 5048 [18], DIN 22101 [4], and CEMA [3] and a number of handbooks suggest various friction coefficients to describe the rolling resistance. They are all subjective. Some only require the dead weight of the belt per unit length, others add idler spacing, belt tension, and ambient temperature and sometimes a constant. Many factors go unaccounted for, such as: idler diameter, idler trough shape, rubber cover thickness, rubber compound, belt stiffness, material load profile, vertical and horizontal curve forces, idler alignment, material and belt center to idler axis, etc. Standard methods, as noted above, are used because they are simple. With small in-plant conveyors, and conveyors with high lift to length ratios, this may be acceptable. With larger overland conveyors, gross errors can be made.

A set of constitutive equations was first proposed by Spaans [19] that described the indention hysteresis loop, in rubber, under deformation by the idler in the manner shown in Fig. 17. These equations have continued to be refined as researchers realized their importance [20] [21] [22].

Three years ago, CDI was awarded a contract, by Syncrude Canada Ltd., to develop a modern viscoelasticity power equation [23]. This work is now essentially complete. The modern power equation has an accuracy of about ±5% of measured condition when all basic information is known. We have been fortunate to assist in the design and commissioning of a number of large projects where accurate field measurements were made:

a. Kennecott's Bingham Canyon UCD Expansion – 1987 (5.5 mile overland, transporting 10,000 st/h).
b. Palabora's Slope Belt – 1988 (9,500 hp; 7.1 MW).
c. Channar 20 km Overland – 1987 (2,100 kW on each of two flights).
d. Phelps Dodge Morenci – 1992 (6,000 hp downhill).
e. Syncrude Canada Ltd. – Present (5,000 hp cold weather (–40 °C) analysis and measurements only).

The field measurement accuracy confirms the theoretical methods. In addition, extensive laboratory work has been conducted on products at full scale for belt, idlers, loading, speed and temperature. Fig. 18 demonstrates the temperature tonnage sensitivity to rubber viscoelastic losses. Note, the friction does not continue to increase with temperature below –20 °C for this compound. At –30 °C, the friction loss is equal to +20° C. The idler bearing losses were not included.

The rubber compound can have a profound influence on power. Fig. 19 illustrates four compound differences. In the extreme, compound A has 4 times the hysteresis drag as the base compound. This equates to more than doubling of conveyor power for a horizontal system.

6. Conclusion

Specifications for belt strength are highly dependent on proper assessment of splice design and construction integrity, and on the accurate analysis of conveyor power. Significant differences exist today between the well-recognized industrial standards and modern engineering principles. The economic impact to the mine owners should not be ignored by the manufacturers. Some, as noted in this paper, are making the necessary changes to offer products which fit today's well-tested technology. Hopefully, this paper will help to bring the industry together and upgrade the standards.

Acknowledgments

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