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Manufacture and application of rubber belting

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MANUFACTURE AND APPLICATION

OF

RUBBER BELTING

BY

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A

THESIS

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RUBBER BELTING

Rubber belting is one of the major products manufactured by the rubber companies and a wide variety of applications is found among many industries. These applications require belts which will meet the needs of the purchasing party both from a cost and a maintenance viewpoint. Belts are installed and operated for two basic purposes, namely, transmission of power and conveyance of material. A well designed installation requires the proper type and size of belting to produce the most economical results for either service. There are many factors to be considered when selecting a belt for a definite service and for that reason a belt generally has special properties which must be recognized.

Transmission and conveyor belting are fundamentally the same for one important factor; this factor is power transmission. Other data are necessary to make and select a belt of the proper type, construction and size.

The subject of rubber belting to be completely descriptive and analyzed to a certain extent must include:

1. Belting materials
2. Processing and manufacture of belting

3. Belt design theories
4. Selection and application of transmission belts.
5. Selection and application of conveyor belts

BELTING MATERIALS.

Belt duck is one of the two basic materials forming the foundation of rubber belts; the second material is properly vulcanized and compounded rubber.

Duck in some instances is 60% of the total weight of a belt. This is especially true of transmission belting where no rubber cover is manufactured on the top and bottom sides of a belt as is the case with conveyor belting.

The duck for transmission belting must be of a definite quality in order that the elasticity in a stretched belt when it is in operation will be correct and yet have a very small amount of permanent stretch. Transmission belt duck must have strength lengthwise to transmit the power load and be sufficiently flexible to pass over the pulleys. The type of weaving must permit perfect impregnation with rubber friction, and the transverse strength and stiffness must be of a definite character to properly hold belt fasteners and give body to the belt. Besides these characteristics already mentioned, conveyor belt duck requires greater transverse flexibility to insure proper troughing over idlers. The elasticity in a belt duck must be sufficiently great so that it will withstand the impact shocks or stresses when heavy lump material falls upon a belt as it is being loaded.

A breaker fabric or cider cloth of very open weave is sometimes required in a conveyor belt when heavy large sized lumps of material are carried. A breaker fabric is placed outside the belt carcass (layers of frictioned duck) and underneath the rubber cover, one on each side of the belt. A rubber friction compound which is soft and flexible fills the interstices in the breaker fabric and provides greater resiliency and a stronger bond between the belt cover and duck. Thus a breaker fabric should be used when severe gouging or cutting action is encountered or when operating conditions tend to actually strip the cover from the belt carcass.

ANALYSIS OF BELT DUCKS

Yarn count			Warp		Fill	
Ounces per square yard	Warp	Fill	Tensile pounds per inch width	Percent elonga-tion	Tensile pounds per inch width	Percent elonga-tion
28	24	14	550	36	240	12
32	22	13	590	36	300	12
35	24	15	700	30	310	10

This table is furnished to show the standard sizes of belt ducks with their characteristics. The yarn count is increased in the warp direction when a harder finish duck is used to give greater longitudinal strength as is the case in transmission belts. A belt which operates under severe service conditions should never be calculated to withstand more than 25 pounds per inch width per ply. This means that the tensile strength of the duck has at the breaking point in the warp direction an ample safety factor.

Ducks for conveyor belts require a definite amount of tensile strength in the warp direction but there are also other factors for special services which must be considered. Heavy lump material requires heavy duck in a belt which provides greater transverse strength and also lower percent elongation. Thirty-five ounce duck is qualified for this service; lighter weight ducks do not have sufficient body. Bridging strength crosswise is required when handling materials, such as wet sand which packs closely, in order to avoid belt creases between the idlers. Transverse strength is obtained by increasing the yarn count in the fill (crosswise) direction or by increasing the yarn size and number of plies in the yarn. Twenty-eight ounce duck is used for belts not over thirty inches wide to convey small size crushed ore, wood pulp, fine coal, cement, light packages, bagged materials, etc. Thirty-two ounce duck replaces twenty-eight ounce duck in belts over thirty inches wide and is termed a general purpose duck. It can be used wherever twenty-eight ounce duck is used and is suitable for ore which is up to eight inches in size. Thirty-five ounce duck fulfills the requirements demanded of a duck for use when large heavy lumps such as hard ores of large size, stone, slate, slag and hard coal are conveyed.

The percentage of elongation in a duck is important because a definite percentage of this elongation is removed when a belt is stretched during vulcanization. This important operation produces a belt which has the correct amount of elasticity when a stretched belt is in service. An improperly stretched belt will elongate excessively and cause power transmission or material conveyance shut-downs.

The proper selection of a belt duck for a belt to meet definite service conditions plays an important part in the operating life of a belt.

RUBBER COMPOUNDS

Rubber compounds make possible the adaptability of rubber belts for many varied working conditions. One cannot feature a modern processing or manufacturing plant operating without rubber belts.

"Rubber compounds" can be briefly described as being composed of the rubber hydrocarbon $(C_5H_8)_x$ into which is incorporated various organic and inorganic materials which alter its physical and chemical characteristics after vulcanization takes place. Rubber compounds present a wide range of physical appearances; some are softer than rubber bands while others are hard as battery cases.

Vulcanization, discovered in 1839, changes the physical properties of a raw rubber compound from a plastic and essentially non-elastic material to one which is non-plastic but elastic. Vulcanization takes place when heat is applied to a raw rubber compound to cause sulphur to combine with the rubber molecule.

Previous to 1906, inorganic materials as litharge and magnesium and calcium oxides were used in rubber compounds to increase the speed of reaction between raw rubber and sulphur.

Since the discovery of the vulcanization of rubber, there have been two outstanding discoveries made which have greatly improved rubber compounds. These discoveries were made by chemists who were employed by The B. F. Goodrich Co. when I was employed by them as a rubber chemist.

The first discovery was the use of organic accelerators by G. Oenslager in 1906. Thiocarbanilide was the organic chemical. Organic accelerators not only greatly reduce the time required for vulcanization but also improve the finished product.

The second discovery referred to is the discovery of antioxidants (ageresistors) by Dr. Winkleman and H. Gray. Antioxidants retard the ageing or oxidation of rubber compounds to increase their useful life 100% or more.

Rubber compounds as applied to belts are of two classes, friction and cover compounds.

Friction compounds are for the purpose of holding the various plies of duck together. It is pressed into the weave of the belt duck, filling the voids between the cotton fibres and also forming a coating around each fibre. Thus a frictioned duck provides a homogeneous structure which is capable of distortion when passing over pulleys without mechanical deterioration.

Transmission belts have only a very thin coating of rubber on the surface, which is a friction compound. Conveyor belts require a rubber cover completely around the carcass of a belt (frictioned plies of duck) to protect the carcass against tearing and abrasion.

A rubber compound consists of raw rubber or raw rubber and reclaim (devulcanized rubber) into which various ingredients are uniformly dispersed by milling. Each ingredient serves a definite purpose. The recipe of a first class friction compound for transmission and conveyor belts is:

	Percent by weight
Raw rubber	87.6
Organic accelerator	.8
Sulphur	2.6
Antioxidants	1.2
Stearic acid	.8
Pine tar	2.5
Zinc oxide	4.5
	100.0

Two ingredients in this recipe will be discussed due to their importance.

The organic accelerator most widely used is mercaptobenzothiasole, $C_6H_4N:C(S)SH$. It is obtained by heating thiocarbanilide and sulphur. There are several types of organic accelerators and of varied chemical structure. Accelerators are quite definitely a study unto themselves.

Antioxidants in belts not only increase the ageing life but also the flexing life. The original anitoxidant, aldol-alpha-naphthylamine, is used in belt frictions to retard heat deterioration. In combination with this antioxidant is used a similar chemical, phenyl-beta-naphthylamine, which retards flex cracking.

Belt cover compounds vary in quality in relation to their ingredients cost. This statement holds true when a rubber chemist uses the most appropriate materials and properly balances the vulcanizing ingredients in a compound. The standard method of evaluating a belt cover is in terms of tensile strength because as a rule the higher the tensile strength, the better is the abrasive resistance and ageing qualities in a belt cover.

Belt covers are of four standard qualities and their ingredient breakdown is tabulated:

GRADE QUALITY	1	2	3	4
Tensile pounds/sq. inch	3500	2500	1500	1000
Crude rubber	67%	39%	22%	9%
Reclaimed rubber	-	36	37.3	67
Carbon black	23.5	17	10	6
Zinc oxide	3.2	2.5	2	2
Clay	-	-	24.75	-
Calcium carbonate	-	-	-	13.8
Pine tar	2.5	2.45	1.5	-
Paraffin wax	.25	.25	.25	-
Accelerator	.90	.60	.30	.50
Antioxidant	.90	.60	.50	.40
Sulphur	1.75	1.60	1.20	1.30
Total percent	100.	100.	100.	100.

One feature of the above breakdown should be noted. As the quality is reduced, denoted by lowering of tensile strength, crude rubber value has been replaced by the rubber value in the reclaim. The reclaim used is obtained by devulcanizing or plasticizing old tires. This type of reclaim contains 50 percent rubber value which is low priced in comparison to crude rubber.

Everyone is familiar with the rubber compound which is used as the tread on a first grade tire. The first belt cover compound has correspondingly the same compounding thought, skill and tests as its background to give it the same wearing quality as a tire tread. The composition of both are similar except that the belt cover is softer because of smaller carbon black content. It is purposely made softer to produce more resiliency in order to better withstand the impact of materials falling upon it.

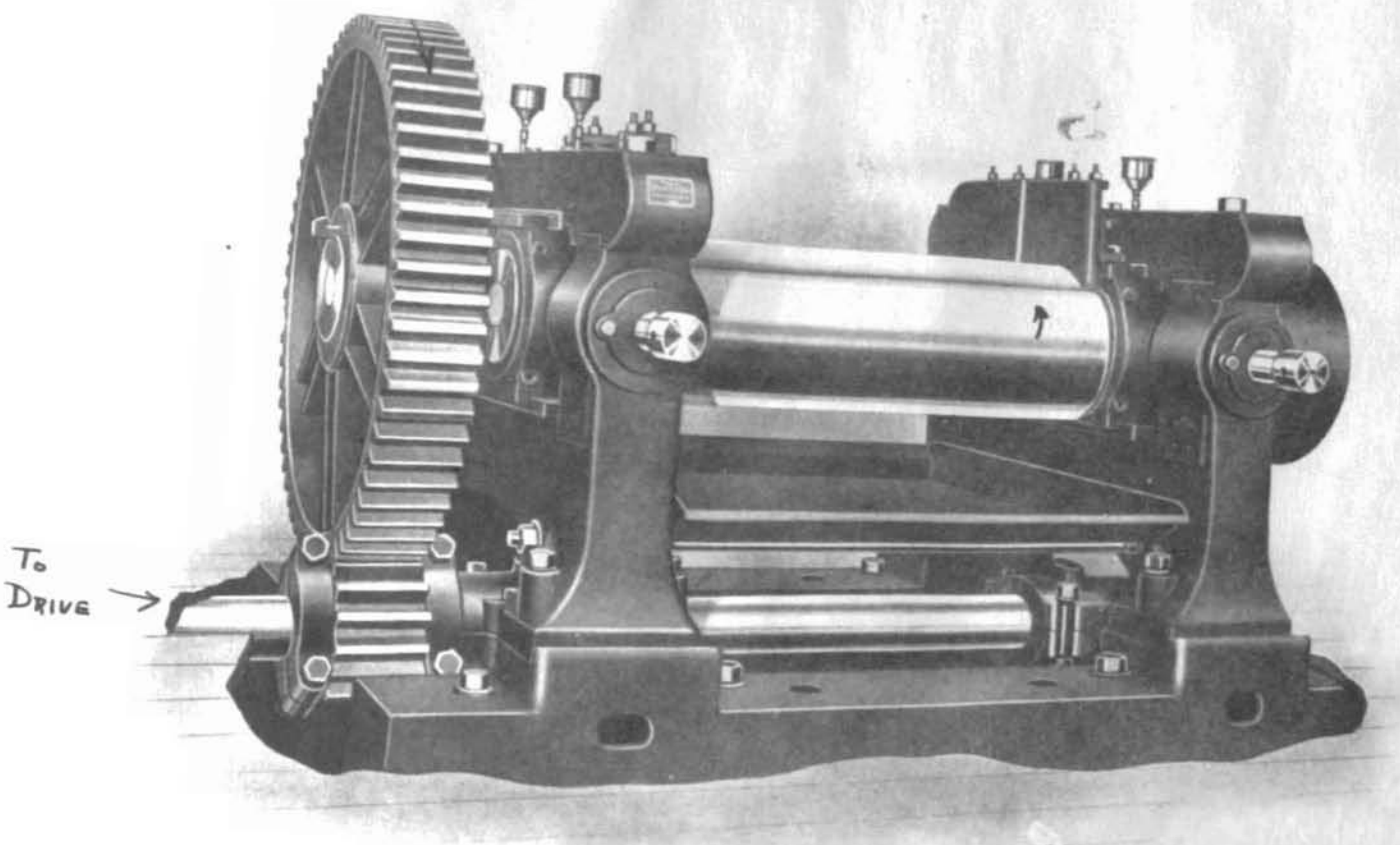
RUBBER COMPOUND PROCESSING

After the various ingredients for a rubber compound are weighed, they are ready for the mixing mill. Mixing is the first mechanical operation. The crude rubber and reclaimed rubber, if any, are placed between two hollow water cooled rolls where squeezing and softening takes place. After the crude and reclaimed rubber is passed several times between these rolls they become soft and plastic, forming one contiquous sheet around one of the rolls. When the proper degree of softness has been obtained, other ingredients are gradually added in the center between the two rolls. The ingredients gradually are worked into the rubber and after good dispersion is obtained, a mill man cuts the mixed compound into slabs and takes it from the mill.

Internal mixing machines have in recent years replaced many two-roll mills previously mentioned, since internal mixers cost on an average only one-fourth as much to operate. An internal mixer consists of two specially shaped rolls rotating in opposite directions within a closed chamber. The rubber is kneaded or mixed in this chamber and the ingredients are thoroughly dispersed as on an open mill.

On the following page is a picture of a two-roll open type mill, and on the succeeding page is a picture of an internal mixer.

MIXING MILL



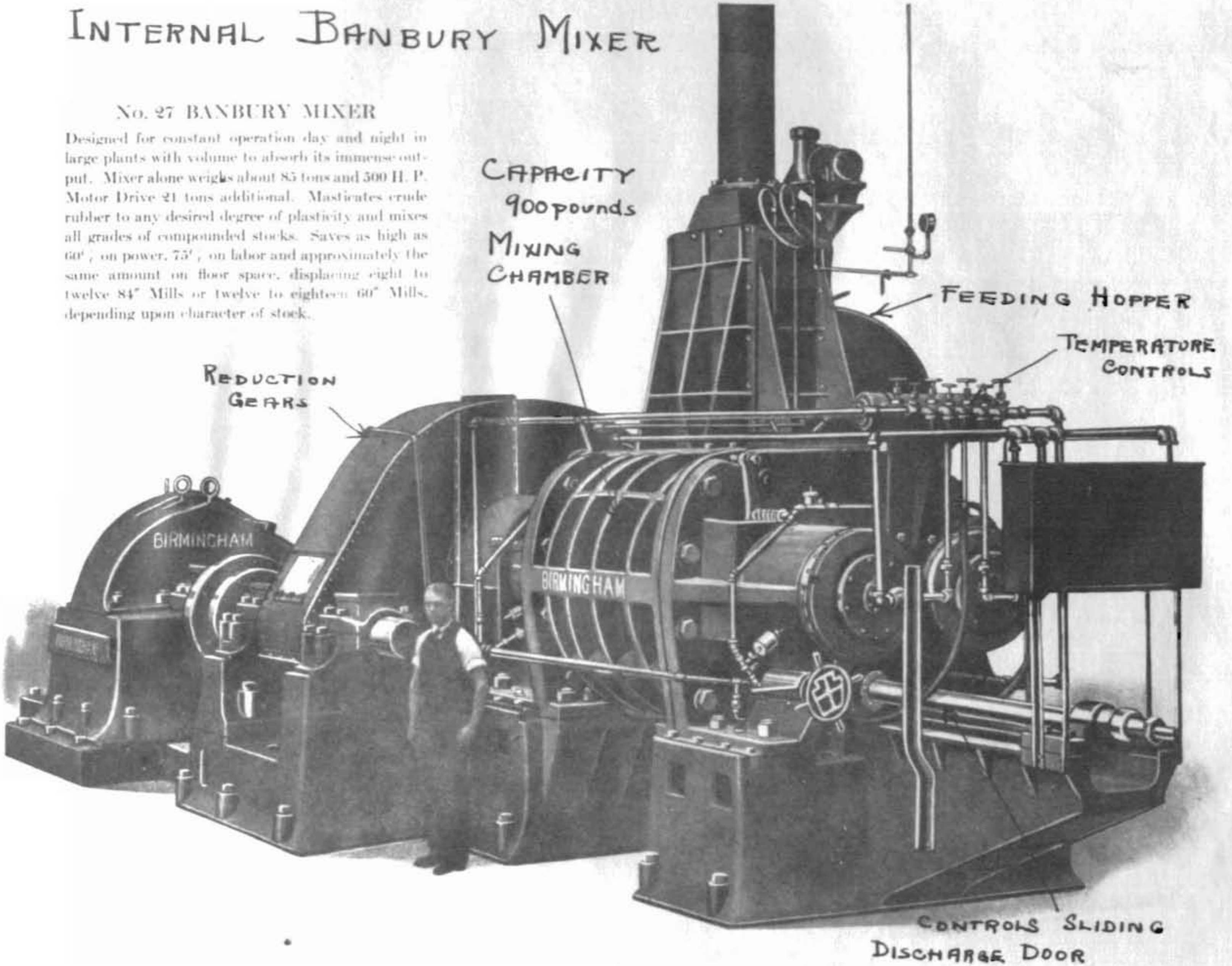
20" & 22" x 60" CHILLED ROLL MILL

Special type of bedplate, cut spur drive gear and pinion, the latter clamped to the shaft. Safety rigging and drive gear guard usually furnished also.

INTERNAL BANBURY MIXER

No. 27 BANBURY MIXER

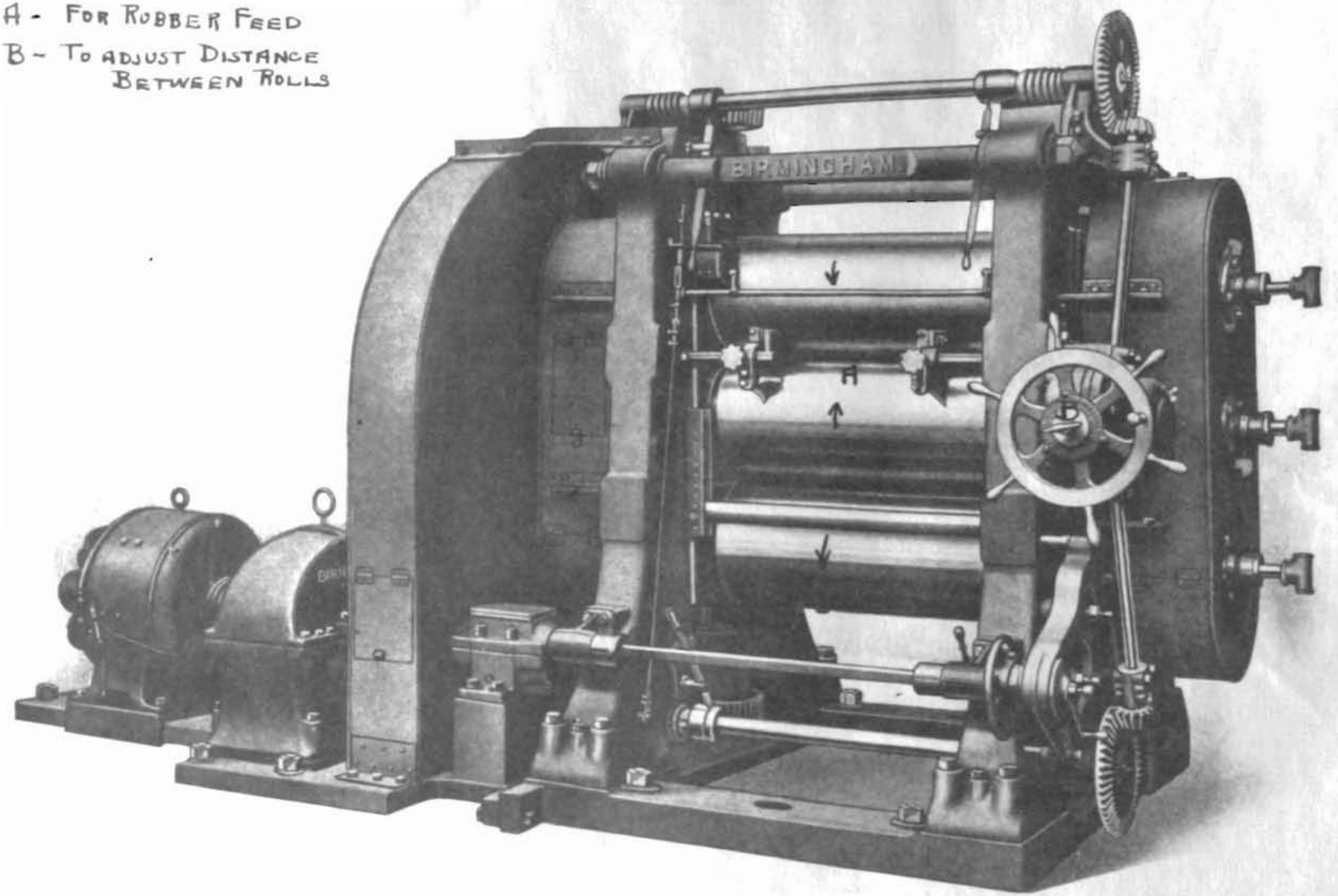
Designed for constant operation day and night in large plants with volume to absorb its immense output. Mixer alone weighs about 85 tons and 500 H. P. Motor Drive 21 tons additional. Masticates crude rubber to any desired degree of plasticity and mixes all grades of compounded stocks. Saves as high as 60%, on power, 75%, on labor and approximately the same amount on floor space, displacing eight to twelve 84" Mills or twelve to eighteen 60" Mills, depending upon character of stock.



FRICTIONING OF BELT DUCK

A calender is a machine required for impregnating duck with a rubber friction compound. The term "friction" is used since the center roll of a three-roll calender has a speed 50 percent greater than the top and bottom rolls. In frictioning duck, rubber which has previously been softened by working on a mill, is placed between the top two rolls and is passed completely around the center roll. All three rolls are maintained at a temperature of about 200 degrees Fahrenheit, this temperature being necessary to keep the rubber very plastic. The duck is inserted and passed between the two bottom rolls and one side frictioned as one operation. The second side is frictioned by passing the duck through the calender a second time. The rubber friction is forced and squeezed into the duck by the friction action of the center roll. Duck must be dried before frictioning by passing it over heated drums. Ducks with excessive moisture do not friction uniformly, and the result is a belt of short life, caused by ply separation. The customary most economical frictioning method is to friction one or more rolls of duck 160 yards long in production.

A - For Rubber Feed
B - To adjust Distance
Between Rolls



18" x 42" THREE-ROLL CALENDER

With standard equipment and driven by direct current motor through Herringbone Gear Reduction. Safety trip for operating dynamic braking on motor. Other sizes in this type, 16" x 30" or 36", 18" x 48" or 50" and 20" x 54", the size depending upon the work for which the Calender is intended.

CALENDERING OF BELT COVERS

Belt covers are sheeted or calendered to the required thickness on a calender. A sheeting calender is identical with a friction calender; however, the speed of the two bottom rolls must be the same, the top roll may be operated at the same speed or a slower speed. Previously mill warmed and softened rubber is fed into the calender between the top two rolls which are adjustable as to the distance that they operate apart. By this method, the belt cover may be calendered to a definite ply thickness. For example, a thin cover may be calendered 1/32" or 1/16" as one ply. Thicker covers are calendered by adding one ply on top of one or more plies until the desired thickness is obtained. After one ply is calendered a second ply is added by running the first ply through the calender from the back side and next to the bottom roll. This operation is repeated until the desired belt cover thickness is obtained. In calendering a good grade belt cover when all three rolls are operating at the same speed, the roll temperatures will be 150 degrees Fahrenheit for the top roll, 160 degrees Fahrenheit for the center roll and 100 degrees Fahrenheit for the bottom roll. The top roll is kept slightly cooler than the center roll in order that the rubber will cling to the center roll. The cooler bottom roll serves the purpose of cooling the rubber surface slightly but without cooling the rubber sufficiently to cause sulphur to bloom to the surface.

SKIM COATING OF FRICTIONED BELT DUCK

In a transmission belt there must be a thin layer of resilient rubber like a friction compound between the duck plies to assist in absorbing the punishment which a transmission belt receives in service. This layer or rubber is termed a "skim coat" because it is only .010" thick. This skim coat is added to the frictioned duck by using the sheeting calender. The frictioned duck is passed through the calender next to the bottom roll and the skim coat pressed upon it with the center roll of the calender.

BELT BUILDUP

The belt duck after frictioning, is built up in the carcass of the belt. The carcass consists of layers of frictioned duck. The processing of the carcass proceeds step by step. To one ply of duck on a table is added another ply, these two plies are then squeezed between two heavy rolls to remove trapped air and to produce a good bond between the plies of duck. These two plies are returned to their original starting position in order to add another ply of duck. This operation is repeated until the required number of plies have been added. Transmission belts require no further labor before vulcanizing.

Conveyor belts have a thickness of rubber added to the top and bottom sides of the carcass in a manner similar to adding the plies of duck. Also narrow strips of rubber thus making the belt carcass completely surrounded with a protective rubber covering. The final step in belt buildup is to dust the belt with talcum, which prevents the belt adhering to the vulcanizing press plates, and then winding the belt into roll form.

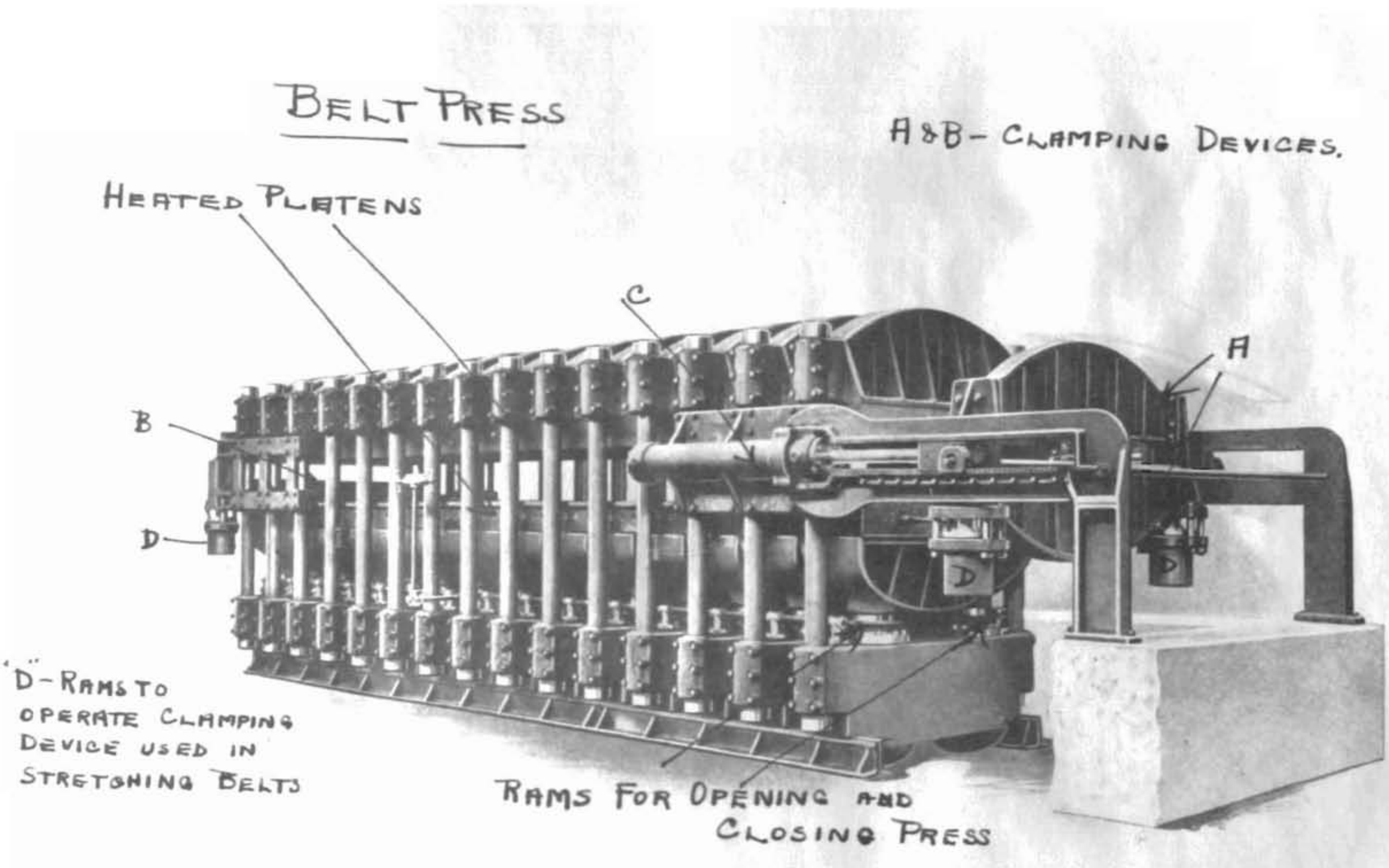
BELT VULCANIZING

Vulcanizing presses are twenty-five to thirty feet long and four to six feet wide. They are hydraulically operated with a two hundred and fifty pound per square inch low water pressure line and one thousand pounds per square inch pressure on the high pressure line. The presses are steam heated and are maintained at the temperature designated by the chemist in charge. This temperature should be close to 281° Fahrenheit

(35 pound steam pressure), which is not high enough to cause any deterioration to the cotton duck fibres from the heat effect taking place during vulcanizing.

The unvulcanized belt in roll form is placed at the end of the press which has the belt stretching apparatus as shown in the picture on page 17a. Through the opened press is drawn a sufficient length of belt so that the end can be clamped in the hydraulically operated clamping device (B) at the opposite end of the press where it is tightly clamped in position by using water pressure secured from the low water pressure line. The belt without being too slack is likewise clamped tight by the clamping device (A) on the press end where the belt in roll form is stationed.

The next highly important operation of stretching the belt is accomplished by moving clamp (A) away from clamp (B) with the hydraulically operated ram (C). A transmission belt requires eight percent stretch in order that the belt will remain tight when running in driving position. Enough elasticity must remain in the belt to protect the machinery from shocks and strains. Conveyor belts are only stretched six percent. They are not operated under the high tension demanded of



74" x 30' 6" HYDRAULIC BELT PRESS

With fixed Hydraulic Stretcher and Hydraulic Clamps. Usual one-piece cylinder construction. Sizes 52", 62", 74" and 86", lengths as required. Two openings if desired, also Movable Stretchers.

transmission belts and are therefore not stretched as much.

The lower platen is raised by applying hydraulic pressure from the low water pressure line. Thus the belt is pressed between the two press platens, and at this stage the clamps which are holding the belt ends are released. The low pressure water line is now closed and more pressure is exerted upon the belt by opening the high water pressure line. This is the operation which has the effect of forcing the rubber into and around the cotton duck fibres. The pressure exerted upon each square inch of belt must be 120 pounds for transmission belts and is increased to 140 pounds for the rubber covered conveyor belts. Higher pressures than these cause the fibres in the duck to become distorted. Laboratory and field flexing tests have proved these pressures to be correct.

The time of vulcanizing is twenty-five minutes for belts one-fourth inch thick, heavier belts require a longer vulcanizing time to allow the center of the belt to reach the temperature impressed upon the belt. The proper degree of vulcanization must be obtained through the whole belt.

After one press length is vulcanized, the press is opened and another press length of unvulcanized belt is pulled into the press and placed in vulcanizing position, where it is processed in the same manner as the first prëss length. This operation is repeated until the belt is completely vulcanized.

Conveyor belts require irons placed along the edges during vulcanization, these serve as a framework to prevent the rubber covers and edges flowing away from the carcass during vulcanization. Were it not for the irons holding the rubber in position during vulcanization, the vulcanized belt would not have the desired thickness. This is due to the fact that rubber becomes a soft flowing mass in the first few minutes of the vulcanizing period before vulcanizing begins to take place. Transmission belting is not confined with irons since it does not have rubber covers.

FINISHING

Transmission belts are cut to width and length from large rolls prepared for this purpose. If they are ordered endless, the ends are step spliced and cemented together, then this section of the belt is given a short vulcanization period to vulcanize the cement. A properly made step splice produces a secion in a belt which is for all practical purposes as lasting as any other section in a belt.

Conveyor belts have a small amount of vulcanized overflow on the edges which must be trimmed off. This is caused by a small amount of rubber flowing between the confining irons and the press platens. The final operation is cutting to required length and splicing the ends together if required.

THEORY OF BELT DESIGN

The theory of belt design in this section will pertain to a discussion of the basic principles underlying power transmission by belting. Various factors influence the quantity of power which will be transmitted by a belt, the important factors are:

1. Arc of contact
2. Coefficient of friction
3. Centrifugal force

Before going into these factors in detail it is necessary to cite some horsepower formulas as related to belts.

On a driven pulley with a belt running, whether it is a transmission or conveyor belt, a difference of belt tension is necessary to transmit power. In a belt there is a tight side tension and a slack side tension. The tight side tension minus the slack side tension is known as the effective force acting: or, $T_1 - T_2 = E$

The horsepower transmitted will be:

$$H.P. = \frac{E \text{ (pounds) x speed (feet per minute)}}{33{,}000 \text{ (foot pounds per minute)}} \quad (I)$$

A transmission belt constructed of plies of duck is easier to evaluate for strength when T_1 and T_2 are calculated in pounds per inch width per ply thickness, which may be expressed as pounds per ply inch, thus the horse power formula (I) becomes:

$$H.P. = \frac{(T_1 - T_2) \quad W \; N \; S}{33{,}000}$$

where T_1 is tight side tension in pounds per ply inch

T_2 is slack side tension in pounds per ply inch

W is width of belt in inches

N is number of plies

S is belt speed in feet per minute

A belt in order to transmit power must grip the pulley, this grip depends upon three factors: the tightness with which a belt grips the pulley due to the tensions exerted upon the belt, the coefficient of friction between the belt and pulley surfaces, and the arc of contact of the belt with the pulley. These three factors are related as follows:

$$\frac{T_1}{T_2} = e^{fa} \qquad (3)$$

where

e is Naperian log base (2.71828)

f is coefficient of friction

a is arc of contact in radians

From this equation we observe that T_2 (slack side tension) bears a definite relationship to T_1 (tight side tension), this relationship or percentage depending upon the coefficient of friction and arc of contact. The effective pull E (T_1-T_2), obtained by rewriting equation (3) with T_2 becoming equal to $T_1-(T_1/e^{fa})$, is:

$$E = T_1 \left(1 - \frac{1}{e^{fa}} \right) \qquad (4)$$

The importance of the coefficient of friction and arc of contact in relation to power capacity is best appreciated by the following comparisons:

Considering first a drive with pulleys of equal size, the arc of contact is 180 degrees (3.1416 radians) and taking 0.25 as a practical acceptable coefficient of friction value, we have:

$$T_1/T_2 = 2.71828 \times 3.1416 \times .25 = 2.19$$

$$T_2 = T_1/2.19 = 45\% \text{ of } T_1.$$

Thus: The effective pull T_1-T_2 equals 55% of T_1.

Consider secondly a drive with the coefficient of friction reduced by oil or dust to .15 and the arc of contact reduced to 120 degrees, then T_1/T_2 is 1.37, and T_2 is 73% of T_1. Thus, T_1-T_2 is 27% of T_1.

Comparing the first and second drives it will be noted that the belt in the second case will transmit only 50% of the power which the first belt will transmit.

CENTRIFUGAL FORCE

Centrifugal force is produced when a belt travels around a pulley and has the effect of reducing the amount of belt tension available for transmitting power. Thus T_1, which has been taken as the permissible tension, is partially rendered useless due to centrifugal tension (Tc) and equation (4) becomes:

Effective tension $= E = (T_1 - T_c) \left(1 - \frac{1}{e^{fa}}\right)$ (5)

Centrifugal tension T_c is obtained from the equation:

$$T_c = \frac{w\ s^2}{3600\ g} \qquad (6)$$

where, w is weight of belt per lineal foot

s is speed of belt in feet per minute

g is 32.2

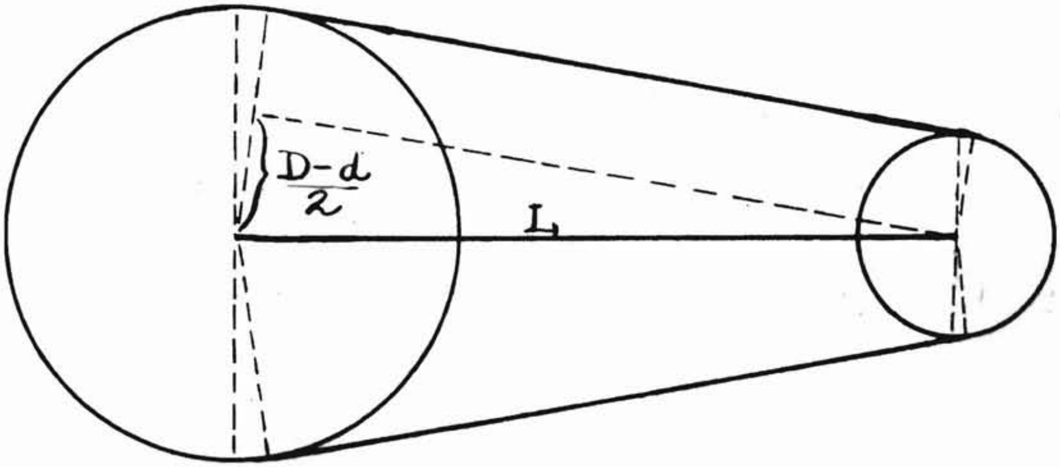
To observe the effect of equation (6), take the example of a five inch wide four ply belt of 28 ounce duck which weighs .50 pounds per foot, the following calculated figures are given when the belt is running at various speeds:

Speed (feet per minute)	2000	3000	4000	5000	6000	7000
T_c in pounds	17	38	69	108	156	216

It is to be noted that with a speed of 2000 feet per minute that the centrifugal force effect is small, but for high speeds this factor must be given due consideration to avoid overtightening a belt.

ARC OF CONTACT CALCULATION

On the following page is shown a sketch on which is based the arc of contact calculations.



For all practical purposes of belt application a simple formula can be developed from the above sketch to calculate the arc of contact. Assuming that an angle in radians is equal to its sine, we have:

$$\text{Arc of Contact} = 180 - 57.3 \left(\frac{D - d}{L} \right) \qquad \text{(in degrees)}$$

Where 57.3 is the factor for converting radians to degrees.

TENSIONS IN DUCKS FOR TRANSMISSION BELTS

The permissible tensions in transmission belt ducks given below show the tensions which must be used for various weights of ducks when calculating belt horsepower strength.

Duck weight	Maximum tight side tension
28 ounce	20 pounds per inch width per ply
32 ounce	24 " " " " " "
35 ounce	27 " " " " " "

APPLICATION OF THEORY TO TRANSMISSION BELTS

The foregoing theory development has been given as a prelude to its practical application.

Let us determine the maximum permissible horsepower rating of a one inch width of a four ply belt made of 28 ounce duck with a speed of 5000 feet per minute, arc of contact 180 degrees and coefficient of friction .25.

Applying formula (5) to formula(1), we have:

$$H.\ P. = \frac{F.\ P.\ M.\ x\ (T_1 - T_c)}{33000} x \left(1 - \frac{1}{e^{fa}}\right)$$

$$= \frac{5000 \quad x \quad (4x20-21)}{33000} x \quad .55$$

$$= \quad 5$$

Table A on the following page is furnished as a base table for the selection of transmission belts, this table shows the maximum permissible horsepower ratings of various belt ducks. As in the example shown above the arc of contact is 180 degrees and the normal coefficient of friction of .25 is taken in calculating the table. Also, the maximum permissible horsepower figure given has been calculated to take into account the effect of centrifugal force.

Belt Duck	Ply	Minimum Pulley Diameter, Inches — Speed in Feet per minute: Under 2000	2000 to 4000	Over 4000	MAXIMUM PERMISSIBLE HORSEPOWER PER INCH OF WIDTH — Speed in feet per minute: 1000	2000	3000	4000	5000	6000
28	3	3	4	5	1.0	2.0	2.8	3.5	3.8	--
ounce	4	5	6	7	1.3	2.7	3.7	4.6	5.0	--
	5	7	8	10	1.7	3.3	4.7	5.7	6.3	--
	6	10	12	16	2.0	4.0	5.6	7.0	7.6	--
32	3	4	5	6	1.2	2.3	3.3	4.1	4.7	5.0
ounce	4	6	8	10	1.6	3.0	4.4	5.5	6.3	6.7
	5	8	10	12	2.0	3.8	5.4	6.9	7.9	8.4
	6	10	12	16	2.4	4.5	6.5	8.3	9.4	10.1
	7	14	16	20	2.8	5.3	7.6	9.7	11.0	11.8
	8	18	20	24	3.2	6.0	8.7	11.0	12.6	13.5
	9	22	24	30	3.6	6.8	9.8	12.5	14.1	15.1
	10	30	36	42	4.0	7.5	10.8	13.8	15.7	16.8
35	3	3	4	5	1.2	2.4	3.5	4.3	4.9	5.3
ounce	4	5	6	8	1.7	3.2	4.7	5.8	6.6	7.2
	5	7	8	10	2.1	4.1	5.9	7.5	8.4	9.0
	6	10	12	14	2.7	5.2	7.5	9.4	10.8	11.4
	7	14	16	18	3.1	6.0	8.7	10.7	12.7	13.3
	8	18	20	22	3.5	6.9	10.0	12.4	14.1	15.2
	9	22	24	28	4.0	7.7	11.2	14.0	15.9	17.1
	10	28	30	36	4.4	8.6	12.4	15.5	17.7	19.0
	12	36	42	48	5.3	10.3	15.0	18.6	21.2	22.8

Since the horsepower value of a belt is not constant as its arc of contact is changed, Table B is furnished as a supplement to be used with Table A. The horsepower value obtained from Table A must be multiplied by one of these factors in Table B when the arc of contact is changed from 180 degrees.

TABLE B.

Arc of Contact	Factor	Arc of Contact	Factor
120 degrees	.74	180 degrees	1.00
130 "	.79	190 "	1.03
140 "	.83	200 "	1.07
150 "	.88	210 "	1.11
160 "	.92	220 "	1.14
170 "	.96		

Tables A and B are based upon a coefficient of friction of 0.25. If the coefficient of friction is lowered or increased, the maximum permissible horsepower is varied accordingly, and the horsepower value from Table A must be multiplied by a factor obtained from Table C.

TABLE C.

Arc of Contact	Coef. of Friction 0.15	Arc of Contact	Coef. of Fric. .35
	Factor		Factor
120 degrees	.50	120 degrees	.96

Table C continued :

130 degrees	.53	130 degrees	1.00
140 "	.57	140 "	1.04
150 "	.60	150 "	1.09
160 "	.64	160 "	1.13
170 "	.68	170 "	1.18
180 "	.71	180 "	1.22
190 "	.73	190 "	1.27
200 "	.75	200 "	1.31
210 "	.78	210 "	1.34
220 "	.81	220 "	1.37

TRANSMISSION BELTING DATA APPLICATION

Let us consider and solve the belting problem of a line shaft pulley of 36 inch diameter with an 8 inch face and a speed of 1650 revolutions per minute. Take 22 horsepower as the estimated maximum peak load and the small pulley with an 8 inch diameter and 6 inch face, and with the center to center pulley distance of 13 feet 7 inches.

With a 6 inch face on the small pulley a 5 inch belt should be used.

22 divided by 5 means 4.4 horsepower required per inch of belt width.

3450 feet per minute is the approximate calculated speed.

Table A shows that a belt speed of 3500 feet per minute for a belt of four ply construction has a permissible horsepower rating of 5.1. There is no need to correct for error caused in using 3500 in place of 3450 feet per minute.

Since Table A is based on an arc of contact of 180 degrees, 5.1 horsepower is too high a rating because by applying the arc of contact formula, it is found in the present case that the arc of contact is 170 degrees. From Table B, the factor for 170 degrees is .96. 5.1 horsepower times .96 is 4.9.

With a greatest applicable belt width of 5 inches, the horsepower rating of the belt would be 4.9 times 5 or 24.5 horsepower.

This horsepower value is entirely satisfactory for a maximum peak load of 22 horsepower.

PULLEY SIZES

Table A has incorporated in it the minimum pulley sizes which should be used for that particular belt. The flexing life of a belt is materially reduced if the pulley size is too small in relation to the thickness of a belt. On any pulley a belt will conform to the surface of the pulley. With the recommended pulley sizes the stresses and strains are taken care of in the belt's construction to give a belt of good flexing life, however, when the pulley size is too small, abnormal stresses and strains are internally created in the belt which have the direct effect of deteriorating the life of the rubber compound which is in the duck and between the plies of duck. The eventual result is ply separation and thus the flexing life of the belt is reduced.

PULLEY FACES

When a belt is applied to pulleys and shafts which are in perfect alignment, the belt will function properly to produce a true running belt. The belt of course must be squarely joined at the ends with fasteners or the splice in the belt must be perfect to uniformly distribute the stresses in the belt. The best practice is to use a belt which is one inch narrower than the pulley face for belts up to six inches wide, for belts of greater width the belt should be two inches narrower than the pulley.

CONVEYOR BELTS

Conveyor belts during the last thirty years have performed an important part in modernizing present day processes and production methods. There are many plants which use conveyor belts for either raw or finished products. We are all familiar with the fact that conveyor belts greatly lessen handling costs for many varied industries, in the mining industry, heavy sharp ores are economically conveyed. Better knowledge of application, better design and better materials in belts have been partly responsible for the increased usefulness of conveyor belts.

Conveyor belt application may be classified:

1. Bulk material handling
2. Package handling
3. Progressive assembly and inspection operations

Bulk materials as ores are particularly adapted for handling by troughed belts, where idlers like the three pulley type with the two outside idler rolls inclined towards the center, cause the belt to form a trough. Spilling is reduced to a minimum and a larger volume of material is conveyed than with flat belts.

Package handling, assembly and inspection work are better handled with flat belts. The mechanical equipment for flat belts is lower in cost but adequate. Flat belts have only 50 percent of the capacity of troughed belts for bulk materials.

A truer picture of conveyor belts will be obtained if we study them from the viewpoint of bulk material handling where the belt is troughed and not carrying the load with a belt entirely in the horizontal plane as is the case with package conveyors. A troughed belt has a number of plies of duck to meet three requirements:

Body
Flexibility
Tensile strength

The number of duck plies in the body or carcass must be of the correct number in order that the belt be stiff enough to carry the load and not crease longitudinally in the bend of the trough and not develop edge weakness.

The flexibility of a belt for troughing does not permit the use of an excessive number of duck plies. It must conform to the carriers by its own weight to secure the guiding action of the center horizontal idler roller.

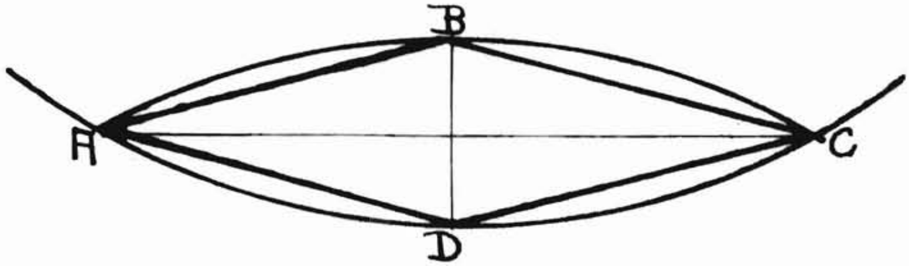
Running a thick belt, which does not have the flexibility of a thinner belt, over a small pulley places a severe strain on the friction rubber between the plies as well as the outer plies themselves. The general practice is to allow 4 inches of drive pulley diameter per ply of duck.

Maximum and Minimum Number of Plies for a conveyor belt.

Belt Width, Inches	Maximum Plies	Minimum Plies	Belt Width, Inches	Maximum Plies	Minimum Plies
10"	4	3	28"	8	5
12"	4	3	30"	8	5
14"	4	3	32"	8	6
16"	5	3	34"	9	6
18"	5	3	36"	9	6
20"	6	4	42"	10	6
22"	6	4	48"	11	6
24"	7	4	54"	12	7
26"	7	5	60"	13	7

The tensile strength of the duck plies is directly related to a safe working stress for the duck in relation to the horsepower required to operate a belt. These factors are later discussed individually.

The capacity of troughed belts is estimated when the weight of material delivered at peak load is unknown. Knowing that a simple formula will not hold true for all widths of belts since on wide belts material can be placed relatively closer to the edges than on narrow belts, it is nevertheless interesting to cite the basic area formula.



The cross-sectional area of average peak load is considered equal to quadrangle ABCD. AC is .8 of the belt's width and BD .2 of the belt's width. The area is thus equal to one-half of .8 width x .2 width or .08 width squared. With the cross-sectional area known, the weight of the material and belt speed, the capacity can be calculated.

On the following page is a table showing the proper belt width and speed for a definite capacity for troughed belts, included are the calculations for materials of various weights per cubic foot. The maximum lump size is also shown for different belt widths.

Carrying Capacity of Troughed Belts

Width of Belt in Inches	Tons (2000 lb.) of Material per Hr. at 100 F. P. M. Belt Speed — Weight of Material in lbs. per Cu.ft. 50	75	100	125	150	Maximum size of Material in inches: Mixed with Fines	Uniform in Size
12	12	18	24	30	36	2	1½
14	17	25	34	42	51	3	2
16	22	33	44	55	66	4	2½
18	28	42	56	70	84	5	3
20	34	51	68	85	102	6	3½
24	50	75	100	125	150	8	4½
30	79	118	158	198	237	12	6
36	114	171	228	285	342	15	8
42	162	243	324	405	486	18	10
48	215	322	430	538	645	22	12
54	270	405	540	675	810	25	13
60	345	517	690	862	1035	28	15

The tonnage capacity of a belt is in proportion to its speed, if it is desired to calculate the tonnage capacity of a belt which is not operating at a speed of 100 feet per minute, its tonnage capacity will be found by taking its speed in relation to 100 and multiplying by a tonnage value in the above table. There are free flowing materials, for example grain, which give a belt 15 percent lower carrying capacity when they are conveyed in troughed belts.

POWER TO DRIVE A CONVEYOR BELT

The power to drive a belt must be known to select the proper belt on an installation. When the actual horsepower consumed is available this information should be utilized in preference to estimating the horsepower. Estimating cannot properly take into consideration operating factors as equipment condition, lubrication, starting strains and over or underloading. On new installations the supplier of the conveyor equipment should furnish the horsepower required for his equipment.

The total or running horsepower used in a conveyor belt unit is dependent on:

A. The power required when the conveyor is running empty.

B. The additional power required to convey the load on the level for a distance equal to the center to center distance.

C. The power demanded to elevate the load or in the case of some conveyors the power generated in lowering the load.

$$\text{HORSEPOWER} = A + B \pm C$$

$$A = \frac{M \times F \times S \times L}{33{,}000}$$

where:

M = Weight of idlers and belt per foot of conveyor, see table M.

F = Friction factor, which varies according to equipment and is approximately:

.05 for ordinary bearings

.03 for antifriction idlers

S = Belt speed in feet per minute

L = Length of conveyor in feet

$$B = \frac{T \times F \times L}{990} \quad \text{(Power to convey on level)}$$

where: T = Tons per hour at peak capacity.

2000T = Pounds material per hour.

60S = Feet of belt travel per hour.

2000T ÷ 60S = Pounds material on each foot of the belt.

F x 2000T/60S x L = Friction force in pounds to convey material on the level.

$$\frac{2000T \times F \times L \times S}{60S \times 33000} = \frac{T \times F \times L}{990} =$$

Horsepower to convey material on level.

C = Power required to raise or lower load

$$= \frac{H \times T}{990} \quad \text{or} \quad .001\ H\ T$$

where: H = Net change of elevation in feet.

2000T÷60 = Pounds material handled per minute as above.

= Rate of work in foot pounds per minute in raising or lowering the load.

Thus: $\dfrac{2000 \ T \ H}{60 \times 33000} = \dfrac{T \ H}{990}$

TABLE M

The value of "M" used in formula A on page 38 is obtained by taking the average carrier spacings on both the carrying and return sides of the belt to obtain an average weight per foot of the center to center distance to which is added the weight of two feet of belting according to its width; the following table represents good average values.

Table M for Values of "M"

Belt Width	M	Belt Wdith	M	Belt Width	M
12	15	20	21	42	49
14	16	24	25	48	59
16	17.5	30	32	54	69
18	19	36	40	60	81

Formulas A and B can be replaced by a formula which has proved its merits in keeping with average practice for the usual types and normal ranges of installations. This formula is worthy of consideration since conveyor equipment is not standardized by manufacturers, differences in design, weight and spacings of equipment will cause any calculated horsepower value to be an estimation.

A + B may be termed level horsepower, and let

Level Horsepower = "N" percent times Tons per hour for each 100 feet between pulley centers.

The value of "N" will change in relation approximately to the weight of the material being conveyed, values are given for "N" in the following table.

Level Horsepower Factor "N" Table N.

Belt Width in Inches	Material Weighing 50 lbs. per cu. ft.		Material Weighing 100 lbs. per cu. ft.	
	Anti-friction idlers	Plain bearing idlers	Anti-friction idlers	Plain bearing idlers
Under 20	1.20%	2.40%	.90%	2.00%
20-24	1.00%	2.00%	.75%	1.50%
30-36	.80%	1.60%	.60%	1.20%
42 and over	.65%	1.30%	.50%	1.00%

Thus a simplification of the running horsepower formula can be utilized and is:

RUNNING HORSEPOWER = "N" x Tons per hour ± formula C.

The estimated horsepower derived from the

the equation on page 41 is that required at the drive pulley to pull the belt. The horsepower at the motor must necessarily be 5-15 percent higher due to the power losses in the head shaft and the driving mechanism.

The factor "N" values referred to in the table are those used by the United States Rubber Company in their technical department and are considered reliable to produce an easy solution to conveyor belting problems without solving A and B formulas separately.

TENSIONS

The effective pull in a belt is the horsepower delivered to the belt times 33000 divided by the speed in feet per minute. The effective pull is known as the "HORSE POWER TENSION".

$$\text{HORSEPOWER TENSION} = \frac{\text{Horsepower} \times 33000}{\text{Speed in feet per minute.}}$$

A belt when running has a definite tension on the slack side to keep the belt from slipping, this is known as the "Slack Tension". Its percentage to the "Horsepower Tension" varies with the type of drive. The "Slack Tension" is found by multiplying the "Horsepower Tension" by a factor "Z".

Values of the Drive Factor "Z"

Arc of Contact		Screw Take-up Bare	Screw Take-up Lagged	Counter Weight Take-up Bare	Counter Weight Take-up Lagged
Average For Single Drives	180°	1.00	.84	.64	.52
	210°	.81	.67	.50	.40
	240°	.66	.55	.40	.32
	270°	.55	.45	.32	.25
	300°	.46	.37	.26	.20
	330°	.39	.31	.22	.16
	360°	.34	.26	.18	.13
Average for Tandem Drives	420°	.25	.19	.13	.09
	450°	.22	.16	.11	.07
	480°	.19	.14	.09	.06

These values of "Z" are obtained by using formula 3 page 22.

TENSION DUE TO WEIGHT OF BELT ON SLOPE

With all inclined conveyors the weight of the belt on the slope causes tension at the top of the slope which may be expressed as follows:

BH = pounds tension due to weight of belt on slope.

Where B = weight of belt in pounds per foot.

H = net change in elevation in feet.

The effect of the belt slope tension on the maximum tension may be neglected for head end drive conveyors which rise not over 100 feet, tail end drive conveyors which rise not over 25 feet and lowering conveyors which drop not over 25 feet. The following approximate table will suffice for most problems:

Percentage to add to "Total Tension"+ for belt slope tension.

TABLE R

Rise "H" in feet	With Drive at Head End	Drive at Tail End
1-24	0	0
25-49	0	5
50-74	0	10
75-99	0	15
100-124	5	20
125-149	8	25
150-174	12	30
175-200	15	35

+The "Total Tension" is the sum of the "H.P. Tension" and the "slack tension" and gives the total tension put into the belt at the drive pulley. This is the maximum tension to be used against the safe working tension.

If table R must be used to secure the maximum tension, the tension obtained by using this table must be added to the "total tension".

DUCK PLIES REQUIRED

After the maximum operating tension in a belt is determined, the next consideration is the number of plies of duck required. The proper duck to use has been discussed under belt ducks.

The number of plies required for withstanding the required tension is determined as follows:

$$\text{Number of plies} = \frac{\text{Maximum tension in pounds}}{\text{M. P. T.} \times \text{Width of belt in inches.}}$$

where— M. P. T = Maximum permissible tension expressed as pounds per ply inch.

The maximum permissible tension in ducks follows:

24 pounds per ply inch for 28 ounce duck
27 " " " " " 32 " "
30 " " " " " 35 " "

These values are capable of withstanding temporary excess strains due to starting under load if the rate of acceleration is not too rapid.

APPLICATION OF PRECEDING CONVEYOR BELT DATA

Take for example a conveyor required to handle run of mine bituminous coal, which weighs 50 pounds per cubic foot; 800 tons per hour required; speed 300 feet per minute; center to center distance 450 feet; height of rise or lift 100 feet; anti-friction idlers; tandem drive with lagged pulleys; 420° arc of contact, located on return side near head end.

Determine: width of belt, approximate horsepower required to drive the belt and number of duck plies required in the belt.

From table H — Tons per hour for a 54" belt with material weighing 50 pounds per cubic foot = 270 x 300/100= Tons

Now to estimate the horsepower required to drive a 54" belt which when operated at capacity handles 810 tons per hour:

Horsepower = 810 x .0065 x 450/100 + 810 x .001 x 100

= 105 Horsepower

Horsepower tension = 105 x 33000/300 = 11550 pounds

Slack tension = 11550 x .09 = 1039 "

Total Tension 12589 "

Maximum Tension = 12589 + 5% (from table R) = 13119 pounds

Duck plies, 32 ounce duck 54 inches has a permissible usable strength of 54 x 27 pounds or 1458 pounds per ply thickness.

12589 ÷ 1458 = 9.

In this example, the width of the belt required is 54 inches, the belt to be constructed of 9 plies of 32 ounce duck and 105 horsepower is to be delivered to the drive pulley.

Factors previously considered have related to horsepower tensions and the strength demanded in a belt under belt operating conditions. Table "Y" that follows is a correlation to show the rubber cover and duck quality required for ordinary materials and under three classes of operating conditions. The grade of rubber used for both the friction and covers should be balanced in quality with the grade of duck used to meet service conditions. Normal service conditions do not justify the cost increase incurred when a 35 ounce duck is used in conjunction with a third grade belt cover and a low priced friction rubber, neither should a 28 ounce duck be used in conjunction with the best rubber cover and friction obtainable.

Class A represents a favorable average of operating conditions and indicates a well-operated installation of best design with no unfavorable conditions.

Class B represents that which is considered average common practice.

Class C represents all hard and severe service, faulty conveyor design, or destructive service conditions.

TABLE Y

Various Materials (cold) with Top Cover Thickness Shown in Fractions of an Inch

GRADE	CLASS	Light or Fine Moderately Abrasive	Fine and Abrasive	Heavy Crushed or Moderately Heavy Lumps		Heavy Sharp Lumps			
				3" size and Under	Run of Mine 8" Lump	Under 3"	3"-8"	Over 8"	
		D+	E+	F+	G+	H+	J+	K+	Duck To Use
1	A	---	1/16	---	1/8	1/8	3/16	3/16	35 oz.
	B	---	3/32	---	3/16	3/16	3/16	1/4	for
	C	---	1/8	---	3/16	3/16	1/4	3/8	heavy
									lumps,
2	A	---	1/16	1/8	1/8	1/8	3/16	3/16	other-
	B	---	1/8	1/8	3/16	3/16	1/4	5/16	wise
	C	---	3/16	3/16	1/4	1/4	5/16	3/8	32 oz.
3	A	1/16	---	1/8	3/16	---	---	---	32
	B	1/16	---	1/8	1/4	---	---	---	or
	C	1/8	---	3/16	5/16	---	---	---	28 oz.
4	A	1/16	---	1/8	---	---	---	---	
	B	1/16	---	3/16	---	---	---	---	28 oz.
	C	1/8	---	3/16	---	---	---	---	

D+ materials are represented by wood chips, fine coal, cement, pulp, soda ash, grain and bagged materials.

E+ materials are represented by sharp sand, clinker, sugar, fine coke, fine slag, salt and sinter.

F^+ materials are represented by concrete, crushed stone, soft ores, sand and gravel.

G^+ materials are represented by soft coal and ores and coke.

H^+, J^+ and K^+ materials are represented by hard ores, stone, hard coal, slate and slag.

INCLINATION ANGLE FOR CONVEYOR BELTS

There is always a maximum angle of inclination to consider when constructing a belt conveyor system. Materials will slide down a belt if it is too steep. There is also the tendency for materials to roll back on themselves and to bounce. The rolling back action causes screened and lump materials to be conveyed at lesser angles than the sliding tendency would require. It is an expensive rebuilding operation to change a conveyor belt system if it has been constructed with the inclination angle too great. The maximum inclination angle for various materials follows:

Wood chips and light, flat materials	27	degrees
Damp sand	24	"
Damp earth and damp slack coal	22	"
Crushed coal, unscreened sand and gravel	20	"
Crushed rock, coke, run-of-mine coal	18	"

Small screened Anthracite coal	17 degrees
Dry sand	15 "
Round objects as pebbles	10-14 "

HOT MATERIAL HANDLING

The handling of hot materials on a rubber belt is a special service which I find interesting. It has been eight years since I made the first successful hot materials belt for a large company which sold it for handling hot silica. Hot fine material as cement, salt, sand and fullers earth can be successfully handled when the proper rubber compounds are used in making a belt. Hot lump materials as rock, clinker, sinter and coke have been successfully conveyed. Hot materials are generally classed as those having a temperature of 150-200°F. Above 200°F., hot material has the effect of reducing the life of a belt. Lump material above 200°F. can be successfully handled provided a heavy rubber cover is used. Large hot lumps touch a belt in spots and may scorch the belt at these contact spots without serious detrimental effect. Air pockets between the lump and the belt serve to retard heat transfer. Belt duck begins to char at about 300°F. Factors effecting handling of hot materials are belt speed and length, and also the manner in which a belt is loaded. Belt speed and length determines the time of contact with the belt's surface. If a material is at an excessive temperature, the hot material may be loaded in the center of the belt. Thus the unhardened edges of the belt serve to keep strength in the side portions of the belt and take up the strains created by the load in the center of the belt.

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