CHAPTER XXXII.—LEATHER BELTING.

THE names of the various parts of a hide of leather as known to commerce are as follows :—

In Fig. 2656 the oblong portion between the two belly parts marked G G is known as the "butt," and when split down the ridge, as shown by the dotted line down the centre, the two pieces are known as "bends;" the two pieces marked Y are "belly offal;" D is known as "cheeks and faces." The butt within the dotted line may extend in length from A to B, or from A to C ; if cut off between B and C that portion is called the "range," or the whole from B to X may be cut in one piece and termed a "shoulder."

Sometimes the range is cut off and the rest would be called a shoulder with "cheeks and faces" on ; or, again, the range and shoulder may be in one nearly square piece. The manner of cutting this part depends upon the spread and size of the hide.

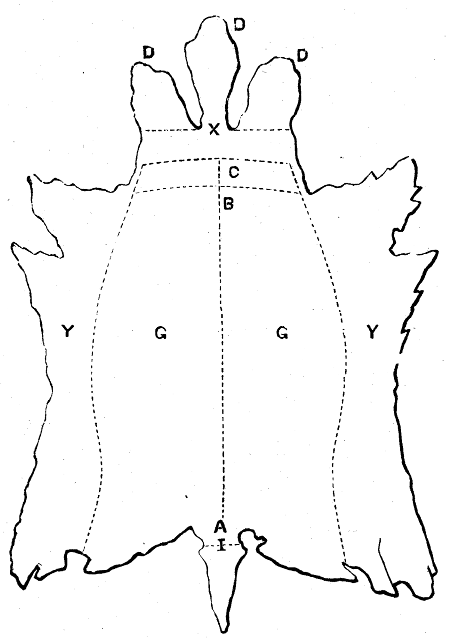


Fig. 2656.

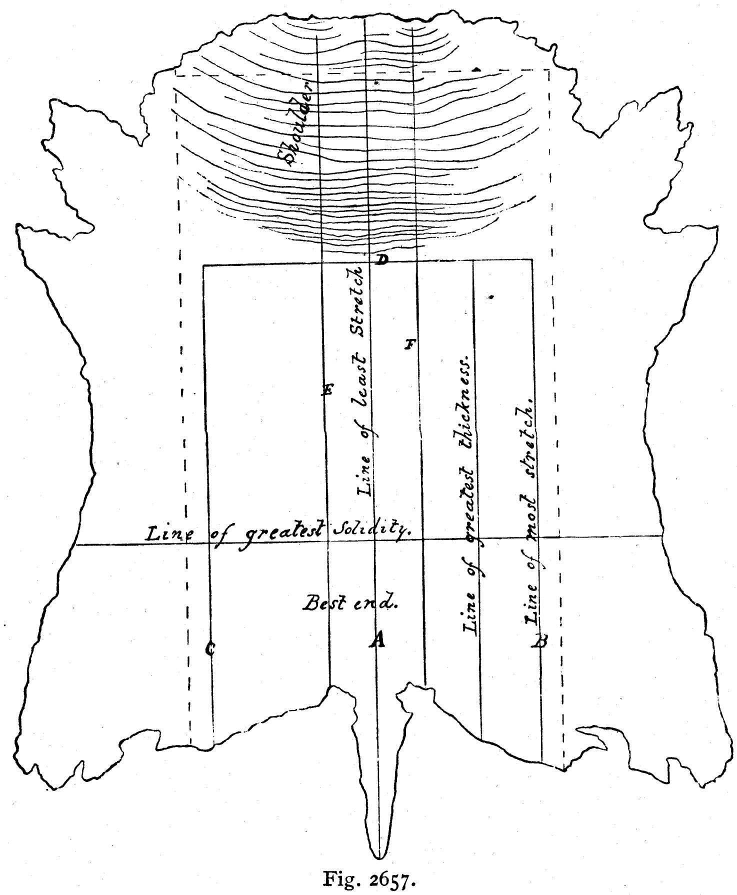


Fig. 2657.

The part of the hide that is used to manufacture the best belting is shown in Fig. 2657, on which the characteristics of the various parts are marked. The piece enclosed by the dotted lines is that employed in the manufacture of the commonest belting, while that enclosed by the full lines B,C,D is that used for the best belting. The former includes the shoulder, which is more soft and spongy, while it contains numerous creases, as shown. These creases are plainly discernible in the belt when made up, and may be looked for near the belt points.

The centre of the length of the hide will stretch the least, and the outer edges on each side of the length of the hide the most. Hence it follows that the only strip of leather in the whole hide that will have an equal amount of stretch on each edge is that cut parallel to line A, and having that line as a centre of its width. All the remaining strips will have more stretch on one edge than on the other, and it follows that, to obtain the best results the leather should be stretched after it is cut into strips, and not as a whole in the hide, or in that part of it employed for the belt strips. It is found, indeed, that, even though stretched in strips, the leather is apt in time to curve. Thus a belt that is straight when rolled in the coil will, on being unrolled, be found to be curved. It is to be observed, also, that each time the width of the strips is reduced, this curving will subsequently take place ; thus, if a belt 8 inches wide and quite straight, be cut into two belts of 4 inches wide, the latter will curve after a short time. The reason of this is almost obvious, because it is plain that the edge that was nearest the centre line of the hide offers the greatest resistance to stretching ; hence, when the strip is stretched straight, and an equilibrium of tension is induced, reducing the width destroys to some extent this equilibrium, and the leather resumes, to some extent, its natural conformation. This, however, is not found to be of great practical importance, so long as the outer curve of one piece is on the same side as the outer curve of its neighbor, as shown on the left view in Fig. 2658, in which case the belt will run straight, notwithstanding its curve ; but if the curves are reversed, as on the right in Fig. 2658, the belt will run crooked, wabbling from side to side on the pulley. To avoid this, small belts may be made continuous by cutting them from the hide, as shown in Fig. 2659 ; but in this case it is better that the belt be cut from the centre strip of the hide

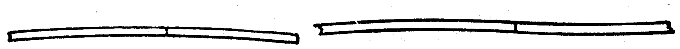


Fig. 2658.

If the leather is stretched in strips after being cut from the hide, the amount of the stretch is about 6 inches in a length of $4\frac{1}{2}$ feet of a belt, say, 4 inches wide, but the stretch will be greater in proportion as the width of the strip is reduced. But if stretched as a whole, the amount of stretch will be about 1 inch per foot of length, the shoulder end stretching one-third more.

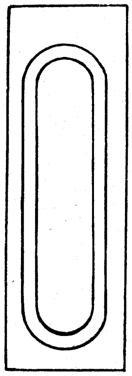


Fig. 2659.

If the leather has been properly stretched in strips the length of the belt may be cut to the length of an ordinary tape line drawn tightly over the pulleys, which allows the same stretch for the belt as there is on the tape line, added to the degree of tension due to cutting the belt too short to an amount equalling its thickness (as would be the case if the belt is cut of the same length as the tape line); or if the belt is a double one, the belt thus cut to length would be too short to an amount equal to twice the thickness of the strips of leather of which it is composed.

When the amount to which the leather has been stretched is an unknown quantity (as is commonly the case), the workman cuts the belt too short, to an amount dictated solely by judgment, following no fixed rule. If, as in the case of narrow belts, the stretching be done by hand, the belt is placed around the pulleys, stretched by hand, and cut too short to an amount dictated by judgment, but which may be stated as about $2\frac{1}{2}$ per cent. of its length.

But the stretch of a belt after it is put to work proceeds very much more rapidly if it has been stretched in the piece and not in the strip, hence it gets slack in the course of a few hours, or of a day or more, according to how much it has been stretched; whereas one properly stretched in the strip will last for weeks, and sometimes for months, without getting too slack.

The results of some experiments made by Messrs. J. B. Hoyt & Co. on the strength of the various parts of a hide are given in Fig. 2660. One side of the part of the hide used for leather belting was divided off into 48 equal divisions, each piece being $11\frac{3}{4}$ inches long, and two inches wide, the results of each test being marked on the respective pieces. The first column is the strain under which the piece broke; the second column is the amount in parts of an inch that the piece stretched previous to breaking; and the third column is the weight of the piece in ounces and drachms.

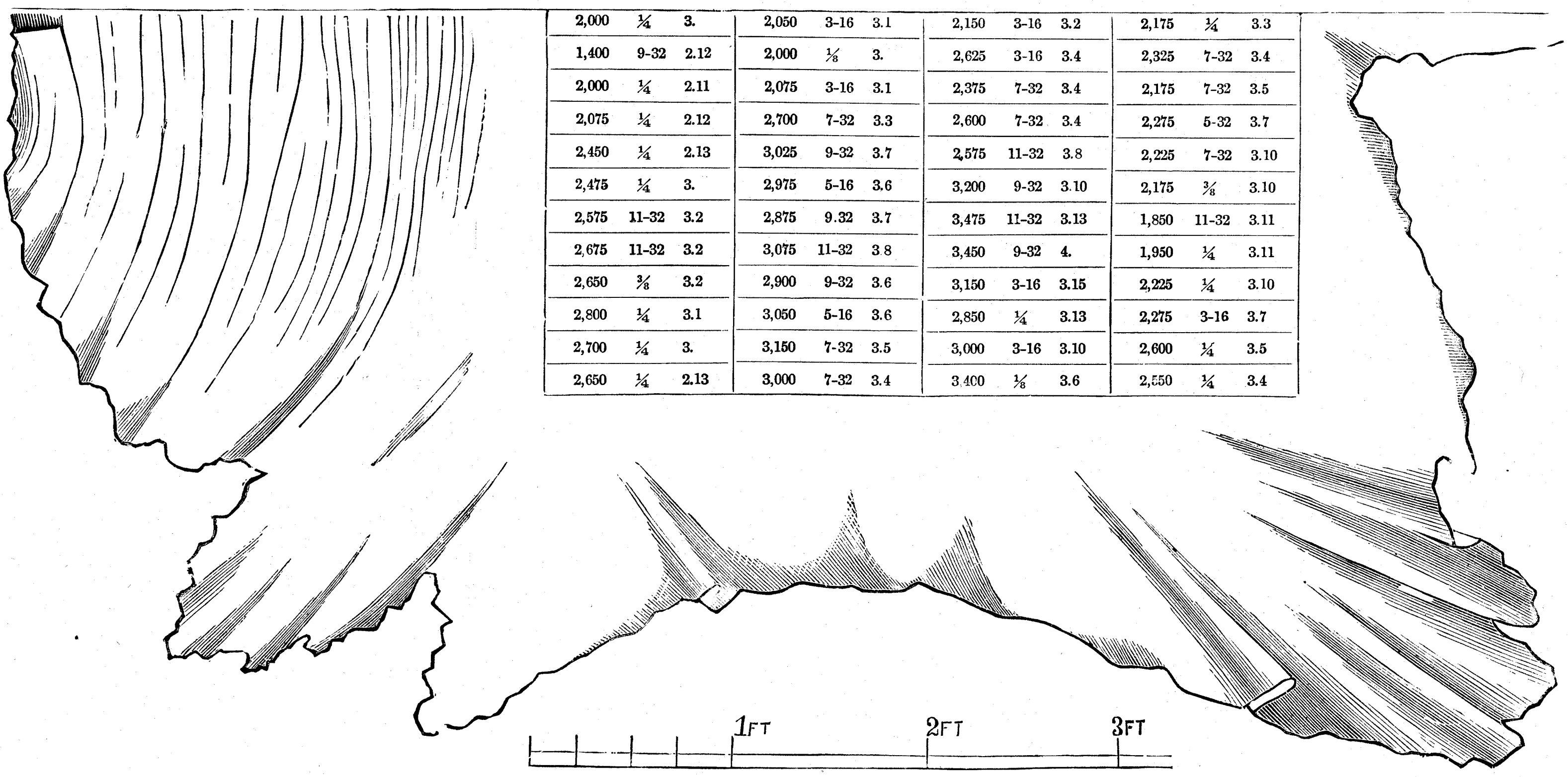
From the table it appears that the centre of the hide which has the most equal stretch has the least textile strength, while in general that which has the most stretch has the greatest textile strength, but at the same time the variations are in many cases abrupt.

A single belt is one composed of a single thickness of leather put together, to form the necessary length, in pieces, riveted and cemented together at the joint, or sewed or pegged as hereafter described.

A double belt is similarly constructed, but is composed of two thicknesses of leather cemented and riveted, pegged, or sewed together throughout its whole length, as hereafter described. The object of a double belt is to increase the strength without increasing the width of the belt. Belts are usually made in long lengths coiled up for ease of transportation, the length of belt required being cut from the coil.

To find the length in a given coil that is closely rolled—Rule: the sum of the diameter of the roll and the eye in inches, multiplied by the number of turns made by the belt, and this product multiplied by the decimal ·1309, will equal length of the belt in feet.

The grain or smooth side of the leather is the weakest, as may be readily found by chamfering it to a thin edge, when it will tear like paper, and a great deal more easily than will the flesh side under similar treatment. Again, it will crack much more readily: thus, take a piece of leather and double it close with the grain side outward, and it will crack, as shown in Fig. 2661 at C, whereas if doubled, however closely, on the flesh side no cracks will appear. If the edge of a clean-cut piece of leather be examined, there will be found extending from the grain side inward a layer of lighter color than the remainder of the belt; and this whole layer is less fibrous and much weaker than the body of the belt, the strongest part of which is on the flesh side. If the grain side is shaved off thin and stretched slightly with the fingers it will exhibit a perfect network of small holes showing where the hair had root. Here, then, we have weakness and excessive liability to crack on the grain side of the leather, and it is obvious



2,000	¼	3.	2,050	3-16	3.1	2,150	3-16	3.2	2,175	¼	3.3
1,400	9-32	2.12	2,000	⅛	3.	2,625	3-16	3.4	2,325	7-32	3.4
2,000	¼	2.11	2,075	3-16	3.1	2,375	7-32	3.4	2,175	7-32	3.5
2,075	¼	2.12	2,700	7-32	3.3	2,600	7-32	3.4	2,275	5-32	3.7
2,450	¼	2.13	3,025	9-32	3.7	2,575	11-32	3.8	2,225	7-32	3.10
2,475	¼	3.	2,975	5-16	3.6	3,200	9-32	3.10	2,175	⅜	3.10
2,575	11-32	3.2	2,875	9.32	3.7	3,475	11-32	3.13	1,850	11-32	3.11
2,675	11-32	3.2	3,075	11-32	3.8	3,450	9-32	4.	1,950	¼	3.11
2,650	⅜	3.2	2,900	9-32	3.6	3,150	3-16	3.15	2,225	¼	3.10
2,800	¼	3.1	3,050	5-16	3.6	2,850	¼	3.13	2,275	3-16	3.7
2,700	¼	3.	3,150	7-32	3.5	3,000	3-16	3.10	2,600	¼	3.5
2,650	¼	2.13	3,000	7-32	3.4	3,400	⅛	3.6	2,550	¼	3.4

Fig. 2660.

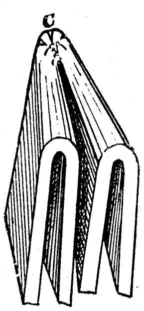


Fig. 2661.

that if this side is the outside of the belt, as in Fig. 2662, at A, the tendency is to stretch and crack it, especially in the case of small pulleys, whereas if the grain side were next to the pulley the tendency would be to compress it, and therefore, rather to prevent either cracking or tearing. Furthermore, very little of the belt's strength is lost by wearing away its weakest side.

Another and important consideration is, that the grain side will lie closest and have most contact over a given area with the pulley surface.

In making double belts of extra good quality, it is not uncommon to cut away or shave off the grain side of both belts, and place those surfaces together in making up the belts.

If the grain side of a belt is the outside when on the pulleys, and a crack should consequently start, the destruction of the belt proceeds rapidly, because the line of crack is the weakest part of

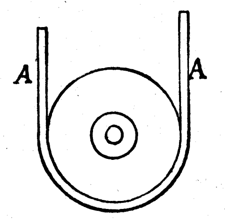


Fig. 2662.

the belt, and the belt has less elasticity as a continuous body, and more at the line of crack. Cracking may, to some extent, be provided against by oiling the belt, and for this purpose nothing is better than castor oil. In the manufacture of belts, extra pliability is induced by an application of fish oil and tallow, applied when the belt (after having been wetted), is in a certain stage of progress toward drying. The oil and tallow are supposed to enter the pores of the leather and supply the place of the evaporated water.

LENGTH OF BELTS.—Since the stretch of a belt is variable in different belts of the same length, no rule can be given for the amount to which a belt should be cut shorter than the measured length around the pulleys, and it follows, therefore, that the length of a belt cannot be obtained precisely by calculation. In practice the necessary length for a belt to pass around pulleys already in their places upon the shaft is usually obtained by passing a tape line or cord around the pulleys, the stretch of the tape line being allowed as that necessary for the belt. Then when the belt is placed around the pulleys it is shortened if it should appear to

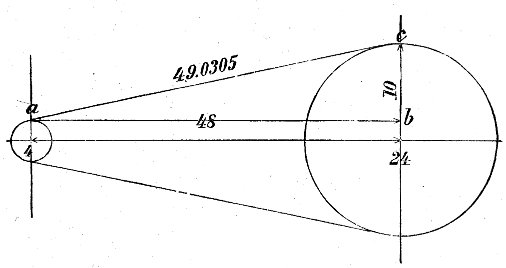


Fig. 2663.

require more tension. If, however, the belt length for pulleys not in position is required, it may be obtained as follows, the error being so slight as to be within the margin of difference of stretch in different belts, and therefore of no practical moment:—

For open belts let the distance between the shaft centres, as *a b* in Fig. 2663, be the base of a right angle triangle, and the difference between the semi-diameters, as *b c*, the perpendicular. Square the base and the perpendicular, and the square root of the sum of the two will give the hypothenuse, and this multiplied by 2 and added to one-half the circumference of each pulley is the required length for the belt. This will give a belt too long to the amount to be cut out of the belt to give it the necessary tension when on the pulleys.

Example.—Let the distance between centres in Fig. 2663 be 48 inches; diameter of large pulley 24 inches; diameter of small pulley 4 inches—

Here distance between centr s	48		
" " "	48		
	384		
	192		
	2304		
Square of perpendicular	100		
	2404	Square root of 2404 =	49·03
		Multiply by 2	2
			98·06
		Half circumference of large pulley	37·699
			135·759
		Half circumference of small pulley	6·283
		Length of belt	142·042

A simpler rule which gives results sufficiently accurate for practical purposes is as follows:—

Rule.—Add the diameter of the two pulleys together, divide the result by 2, and multiply the quotient by $3\frac{1}{4}$, then add this product to twice the distance between the centres of the shafts, and you have the length required.

When the length of a crossed belt is required, and the pulleys are not erected upon the shafts, it is, on account of the abstruseness

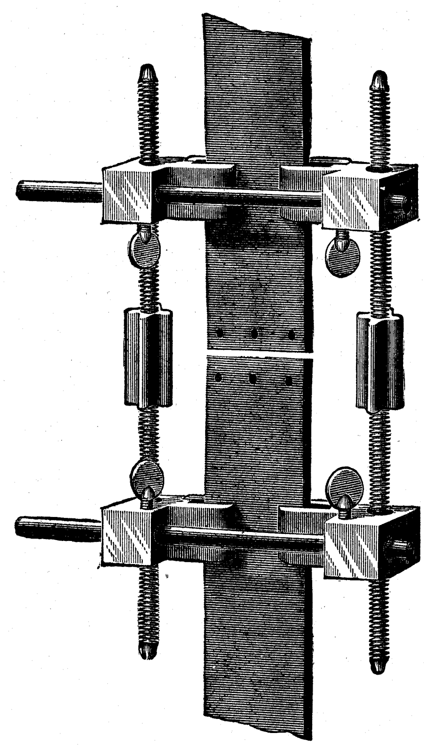


Fig. 2664.

of a calculation for the purpose, preferred in workshop practice to mark off by lines the pulleys set at their proper distance apart (either full size or to scale), and measure the length of the side of the belt, supposing the belt to envelop one-half the circumference only of each pulley, and to add to this one-half the circumference of each pulley; or if there is a great difference between the relative diameters of the pulleys and the distance apart of the shafts is unusually small, the lengths of the straight sides of the belt are measured and the arcs of contact around the pulleys are stepped around by compasses, the set of the compasses being not more than about one-tenth the circumference of the pulleys. This gives a more near result than that obtained by calculation, because although it will give a belt shorter than by calculation, yet the belt will be too long on account of the stretch necessary to the tension required for ordinary conditions.

In narrow belts, as, say, three inches and less in width, the belt may be cut to the length of a tape line passed over the pulleys, and when placed over the pulleys it may be strained under a hand pull and cut as much shorter as the tension under hand pressure indicates as being necessary.

But if the belt is a wide one a stretching clamp, such as shown in Fig. 2664, is employed, the screws being right hand at one end and left hand at the other, so that operating them draws the clamps, and therefore the ends of the belt, together.

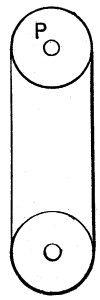


Fig. 2665.

The stretch of a belt not stretched in the piece proceeds slowly when the belt is at work, hence if laced at first to a proper degree of tension it will get slacker in a few hours or in a day or so, and must be tightened, or taken up as it is termed, by cutting a piece out. For this purpose a butt joint possesses the advantage that the piece to be taken out may be less, and still leave the end clear for new holes to be punched, than is the case with a lap joint, which occurs because the butt joint occupies a shorter length of the belt than is the case with a lap joint.

When a belt is under tension upon two pulleys and at rest, the friction or grip of the belt upon the respective pulleys (supposing them to be of the same diameter and therefore to have the same arc and area of contact) will depend upon the relative positions of the pulleys; thus suppose one pulley to be above the other as in Fig. 2665, the upper pulley P will have the grip due to the tension

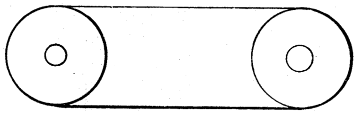


Fig. 2666.

of the belt added to that due to the weight of the belt, whereas if placed horizontally, as in Fig. 2666, the weight of the belt will fall equally on the two pulleys, and for this reason vertical belts of a given width require to have a greater tension to transmit the same amount of power as the same belt would if placed horizontally. But as soon as motion was transmitted, by the belt, from one pulley to the other, the belt on one side of the pulley would be under greater tension then that on the other.

Suppose, for example, a belt to transmit motion and power from

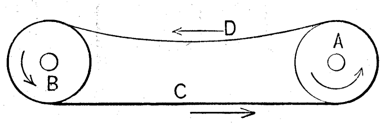


Fig. 2667.

pulley A in Fig. 2667, to pulley B, then the side C of the belt is that which drives or pulls B, and it is therefore called the driving side of the belt, the resistance to rotation offered by B causing the driving side of the belt to be the most strained; and hence the straightest, whereas the side D will be free of the tension due to the resistance of B.

But if the direction of motion be reversed as in Fig. 2668, A still being the driving pulley, the side D will be the one most tightly strained, and therefore, the driving side of the belt; or, in

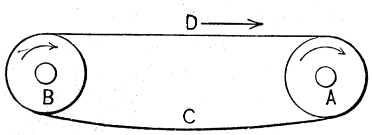


Fig. 2668.

other words, the driving side of a belt is always that side which approaches the driving pulley, and the slack side is always that which recedes from the driving pulley. In horizontal belts, however, the driving side of the belt is not a straight line, because of the belt sagging from its own weight no matter how tightly it may be strained, but the shorter the belt the less the sag.

It is always, therefore, desirable, so far as the driving power of the belt is concerned, to have the lower half (of belts running horizontally) the driving side, because in that case the sag of the belt causes it to envelop a greater arc of the pulley, which increases its driving power. If the circumstances will not permit this and the sag of the belt operates to practically incapacitate the belt for its duty, what is termed an idle wheel or idler may be employed as shown in Fig. 2669 at E, serving to prevent the sag and to cause the belt on the driving side to envelop a greater portion of the pulley's circumference, and hence increase its friction on the pulley and therefore its driving power. In the example the two pulleys A and B are of equal diameters; hence the idle wheel is placed midway between them, but when such is not the case the idle wheel should be located according to the circumstances and the following considerations. The idle wheel requires a certain amount of power to drive it, and this amount will be

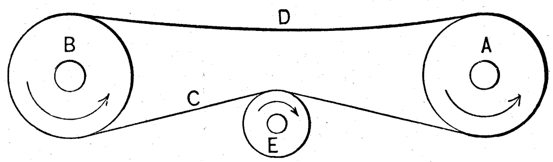


Fig 2669.

greater as the idle wheel is nearer to the smallest wheel of the pair connected; but on the other hand, the closer the idle wheel to the small pulley (all other factors being equal) the greater the arc of small pulley surface enveloped by the belt, and hence the greater the belt's driving power. When therefore a maximum increase of driving power is required, the idler must be placed near to the smallest pulley, the desired effect being paid for in the increased amount of motive power required to rotate the driving pulley.

But under equal conditions the larger the diameter of the idle wheel the less the power required to drive it, because the less its friction on its journal bearing. A belt tightener should whenever practicable be placed on the slack side of the belt.

Belt tighteners are sometimes used to give intermittent motion, as in the case of trip hammers; the belt being vertical is made long enough to run loose, until the tightening pulley closes the belt upon the pulley, taking up its slack and increasing the arc of contact.

When the direction of rotation of the driven pulley requires to be reversed from that of the driving pulley, the belt is crossed as in Fig. 2670. A crossed belt has a greater transmitting power than one uncrossed (or, as it is termed, than an "open belt") because it envelops a greater arc of both pulleys' circumference. This is often of great advantage where the two pulleys are of widely varying diameter, especially if the small pulley requires to transmit much power, and be of very small diameter.

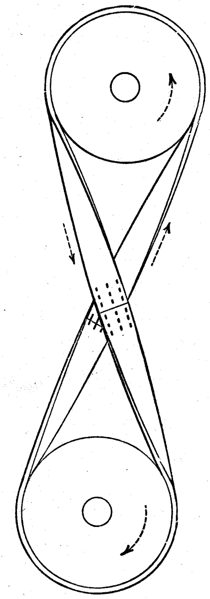


Fig. 2670.

But a crossed belt is open to the objection that the surfaces of the belt rub against each other at the point of crossing, which tends to rapidly wear out the laced joint of the belt. By crossing a vertical belt the lower pulley receives part of the weight of the belt.

When a belt connects two pulleys whose respective planes of revolution are at an angle one to the other, it is necessary that the centre line of the length of the belt shall approach the pulley in the plane of the pulley's revolution, which is sufficient irrespective of the line of motion of the belt when receding from the pulley. This is shown in Fig. 2671, which represents what is known as a quarter twist; A,B are two pulleys having their planes of revolution at a right angle, the belt travelling as denoted by the arrows, then the centre line C of the belt being in the plane of rotation of A on the side on which it advances to A, the belt will continue to run upon the same section of A. If the pulley positions be reversed, as in Fig. 2672, the same rule applies, and the side D in the figure being that which advances upon B must travel to B in the plane of B's rotation, otherwise the belt would run off the pulley; hence it is obvious that the belt motion must occur in the one direction only.

Shafts at any angle one to another may have motion communicated from one to the other by a similar belt connection, providing that a line at a right angle to the axis of one shaft forms

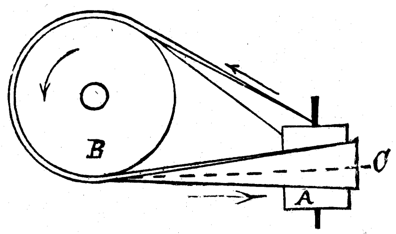


Fig. 2671

also a right angle with the axis of the other. Thus in Fig 2673 the axis of shaft A may be set at any required angle to the plane of rotation of pulley B, provided that the axial line of A be made to lie at a right angle to the imaginary line *l*, which is at a right angle to the axis of the shaft of B, and that the side of the driving pulley which delivers the belt (as C, Fig. 2671) is in line with the centre line of the driven pulley, as denoted by the dotted line C.

But when this provision cannot be carried out, pulleys to guide

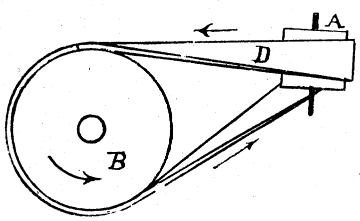


Fig. 2672.

the direction of motion of the belt must be employed; thus in Fig. 2674 are an elevation and plan* of an arrangement of these guide or mule pulleys; A B is the intersection of the middle planes E E and F F of the pulleys P and P′ to be connected by belt. Select any two points, A and B, on this line and draw tangents A C, B D to the principal pulleys. Then C A C and D B D are suitable

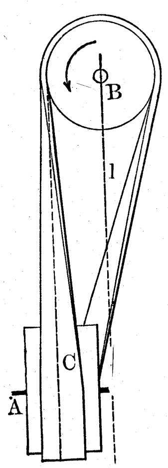


Fig. 2673.

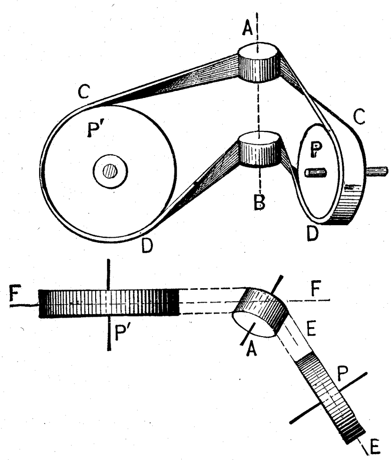


Fig. 2674.

directions for the belt. The guide pulleys must be placed with their middle planes coinciding with the planes C A C, D B D, and the belt will then run in either direction.

In Fig. 2675 is an arrangement of guide pulleys by which two pulleys not in the same plane are connected, while the arc of contact of the smaller pulley C is increased by the idlers or guide

* From Unwin's "Elements of Machine Design."

pulleys A B, while either C or D may be driven running in either direction.

In Fig. 2676 is shown Cresson's adjustable mule pulley stand, which is a device for carrying guide pulleys, and admitting of their adjustment in any direction. Thus the vertical post being cylindrical, the brackets can be swung around upon it and

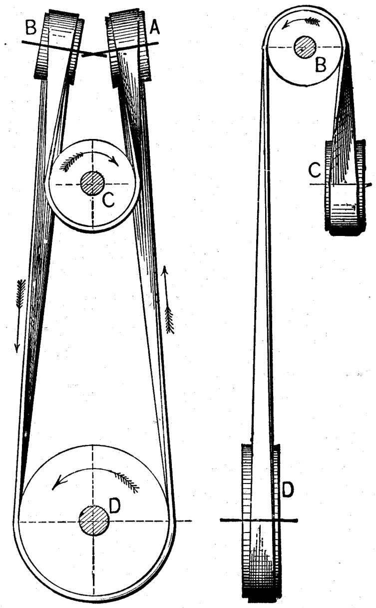


Fig. 2675.

fastened in the required position by the set-screws shown. The brackets carrying the pulleys are also capable of being swung in a plane at a right angle to the axis of the guide pulleys, and between these two movements any desired pulley angle may be obtained. It is obvious that by moving the brackets along the cylindrical post their distance apart may be regulated.

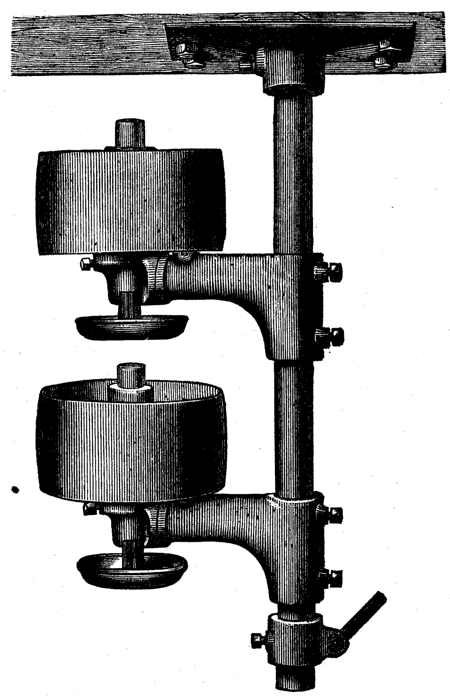


Fig. 2676.

When a belt is stretched upon two pulleys and remains at rest there will be an equal tension on all parts of the belt (that is to say, independent of its weight, which would cause increased tension as the points of support on the pulleys are approached from the centre of the belt between the two pulley shafts); but so soon as motion begins and power is transmitted this equality ceases, for the following reasons :—

In the accompanying illustration, Fig. 2677, A is the driving and B the driven pulley, rotating as denoted by the arrows; hence C is the driving and D the slack side of the belt. Now let us examine how this slackness is induced. It is obvious that pulley A rotates pulley B through the medium of the side C only of the belt, and from the resistance offered by the load on B, the belt stretches on the side C. The elongation of the belt due to this stretch, pulley A takes up and transfers to side D, relieving it of tension and inducing its slackness. The belt therefore meets pulley B at the point of first contact, E, slack and unstretched, and leaves it at F, under the maximum of tension due to driving B. While, therefore, a point in the belt is travelling from E to F, it passes from a state of minimum to one of maximum tension. This tension proceeds by a regular increment, whose amount at

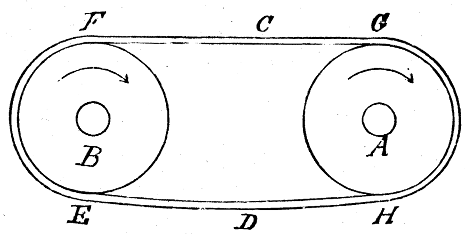


Fig. 2677.

any given point upon B is governed by the distance of that point from E. The increase of tension is, of course, accompanied by a corresponding degree of belt stretch, and therefore of belt length; and as a result, the velocity of that part of the belt on pulley B is greater than the velocity of any part on the slack side of the belt; hence the velocity of the pulley is also greater than that of the slack side of the belt. In the case of pulley A the belt meets it at G under a maximum of tension, and therefore of stretch, but leaves it at H under a minimum of tension and stretch, so that while passing from G to H the belt contracts, creeping or slipping back on the pulley, and therefore effecting a reduction of belt velocity below that of the pulley. To summarize, then, the velocity of the part of the belt enveloping A is less than that of A to the amount of the creep; hence the velocity of the slack side of the belt is that of A minus the belt creep on A. The velocity of the part of the belt on B is equal to that of the slack side of the belt plus the

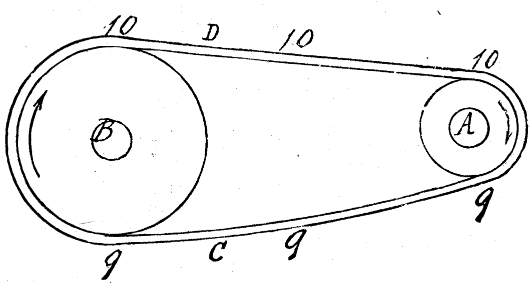


Fig. 2678.

stretch of the belt while passing over B; and it follows that if the belt or slip creep on one pulley is equal in amount to the belt stretch on the other, the velocities of the two pulleys will be equal.

Now (supposing the elasticity of the belt to remain constant, so that no permanent stretch takes place) it is obvious that the belt-shortening which accompanies its release from tension can only equal the amount of elongation which occurs from the tension; hence, no matter what the size of the pulleys, the creep is always equal in amount to the stretch, and the velocity ratio of the driven pulley will (after the increase of belt length due to the stretch is once transferred to the slack side of the belt) always be equal to that of the driving pulley, no matter what the relative diameters of the pulleys may be. In Fig. 2678, for example, are two pulleys, A and B, the circumference of A being 10 inches, while that of B is 20; and suppose that the stretch of the belt is an inch in a revolution of A (A being the driving pulley). Suppose the revolutions of A to be one per minute, then the velocity of the belt where it envelops A and B, and on the sides C and D, will be as respectively marked.

Thus the creep being an inch per revolution of A, the belt velocity on the side C will be nine inches per minute, and its stretch on B being an inch, the velocity of B will be ten inches per minute, which is equal to the velocity of the driving pulley.

It is to be observed, however, that since A receives its motion independently of the belt, its motion is independent of the creep, which affects the belt velocity only: but in the case of B, which receives its motion from the belt, it remains to be seen if stretch is uniform in amount from the moment it meets this pulley until it leaves it, for unless this be the case, the belt will be moving faster than the pulley at some part of the arc of contact.

Thus suppose P, Fig. 2679, represents a driven pulley, whose load is 1,000 pounds, and that from A to B, from B to C, from C to D, and from D to E, represent equal arcs of contact between belt and pulley, then arc A B will have on it the amount of stretch due to a pull of 250 pounds at B, diminishing to nothing at A. Arc C B will have on it the amount of stretch due to a pull of 500 pounds at C and 250 at B; arc D C will have on it the amount of stretch due to a load of 750 at D, and 500 at C; and arc D E will have the tension due to a load of 1,000 pounds at E, and 750 pounds at D. Suppose, then, that the amount of belt stretch is greater between B and C than it is between D and

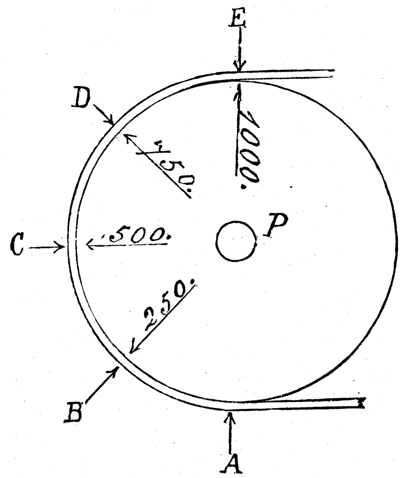


Fig. 2679.

E, then the belt will travel faster between B C than between D E to an amount equal to the difference in stretch, and will at B C slip over the pulley to that amount; or if the friction of the belt at B C is sufficient to move the pulley in accordance with the stretch, then the belt must move the pulley at a greater velocity than the belt motion from D to E.

But since the friction of the belt is greatest at D E, it will hold the pulley with the greatest force, and hence the velocity of the belt and pulley will be uniform, or at least the most uniform, at D E.

Here arises another consideration, in that the stretch of the leather is not uniform, and the section of belt at C B may stretch more or less under its load than section C D does under its load, in which event the velocities of the respective belt sections cannot be uniform, and to whatever amount belt slip ensues the velocity of the driven wheel will be less than that of the driver.

Attention has thus far been directed to the relative velocities of the pulleys while under continuous motion. But let us now examine the relative velocities when the two pulleys are first put in motion. Suppose, then, the belt and pulley to be at rest with an equal degree of tension (independently of the weight of the belt, as before) on both sides of the belt. On motion being imparted to the driving pulley, the amount of belt elongation due to the stress of the load on the driving pulley has first to be taken up and transferred to the slack side of the belt, and during such transfer a creep is taking place on the arc of belt contact on the driving pulley.

Furthermore, let it be noted that while under continuous motion the belt first receives full stress at point F, Fig. 2677; at starting it first receives it at point E, and there will be a period of time during which the belt stretch will proceed from E towards F, the pulley remaining motionless. The length of duration of this period will, in a belt of a given width, and having a given arc of contact on the driven pulley, depend on the amount of the load. Thus, referring to Fig. 2680, if the amount of the load is such that the arc of contact between the top and the point B is sufficient to drive the pulley, the pulley will receive motion

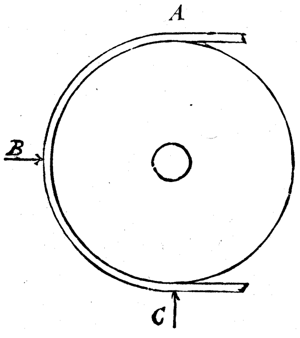


Fig 2680.

when the belt stretch has proceeded from A to B; but if the load on the pulley be increased the belt stretch will require to proceed farther towards C.

At the top the stretch will proceed simultaneously with that of the driving side of the belt, between the points F G, Fig. 2677; but from the friction between the belt and pulley, the stretch of the part enveloping the pulley will be subsequent and progressive from F towards E, Fig. 2677.

It follows, then, that the velocity of the driven wheel will be less than that of the driver at first starting than when in continuous motion.

As the length of the belt is increased, the gross amount of stretch, under any given condition, increases, and hence the longer the belt, the greater the variation of velocity at first starting between the driven pulley and the driver.

From what has been said, it follows that when a mathematically equal velocity ratio is essential, belts cannot be employed, but the elasticity that disturbs the velocity ratio possesses the quality of acting as a cushion, modifying on one pulley any shocks, sudden strains, or jars existing on the other, while the longer the belt and less strained within the limit of elasticity, the greater this

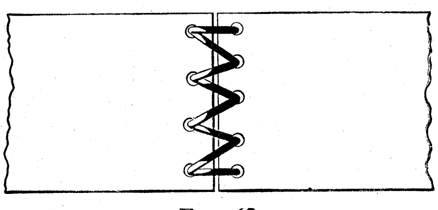


Fig. 2681.

power of modification; furthermore in case of a sudden or violent increase of load, the belt will slide on the pulley, and in most cases slip off it, thus preventing the breakage of parts of the driving gear or of the machine driven that would otherwise probably ensue. Furthermore, belt connections are lighter and cheaper than gear-wheel or other rigid and positive connections, and hence the wide application of leather belts for the transmission of power, notwithstanding the slight variations of pulley velocity ratio due to the unequal elasticity of the various parts of the leather composing the belt.

The ends of belts are joined by two principal methods, the butt and the lap joint. In butt joints the holes are pierced near the ends of the belts, and the ends of the belt are brought together by means of a leather lace threaded through these holes. If the duty is light a single row of holes is all that is necessary. An example of this kind is shown in Fig. 2681, in which there are five holes on one side, and four on the other of the joint, the extra hole coming in the middle of its end of the belt. The lace is drawn half-way through this extra hole, and laced each way to the side and back again to the middle, the ends being tied on the outside of the belt, which does not come in contact with the pulley surface. By this means the lacing is double through all the holes, and if the knot should slip the slackness will begin at the middle of the belt and extend gradually towards the edges; whereas, if the lacing terminated at one side, and the knot or fastening should slip, all the tension would be thrown on one edge of the belt, unduly stretching it, and rendering it liable to tear. By this

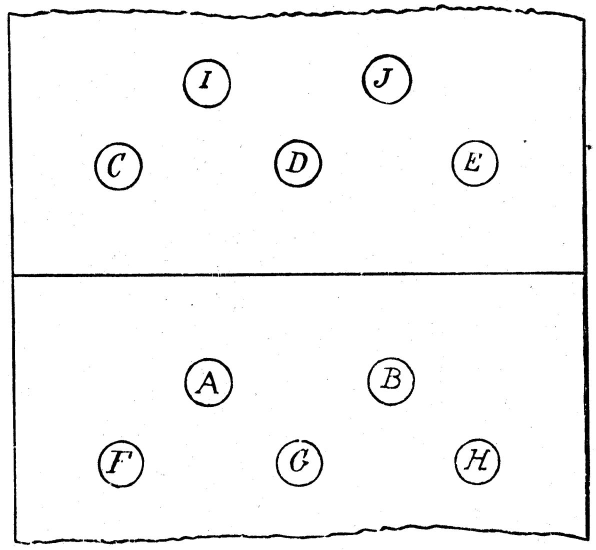


Fig. 2682.

method of lacing the lace is not crossed on either side of the belt, which is desirable, because it is found in practice that a crossed lace does not operate so well as an uncrossed one.

If the power to be transmitted is so much as to render it desirable to have the strength of the laced joint more nearly approach that of the solid belt than is obtainable with a single row of holes, a double row is provided, as shown in Fig. 2682.

For belts of about 3 inches wide and over, these holes are made as follows: A, B, and C, D, E, about an inch apart and $\frac{5}{8}$ inch from the line of joint; F, G, H, and I, J, being about $\frac{1}{2}$ inch behind A, B, and C, D, E, respectively.

For thinner belts the holes may be closer together, and to the edges of the belt the exact distances permissible being closer together as the duty is lighter; but however narrow the width of the belt, it should contain at least two holes on each side of the

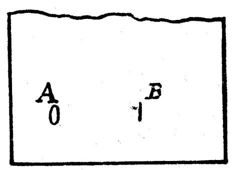


Fig. 2683.

joint. The sizes of these holes are an important element, since the larger the hole the more the belt is weakened. The following are the sizes of holes employed in the best practice:—

Width of Belt.	Size of Punched Hole.
Up to 4 inches	$\frac{1}{4}$ inch.
From 4 to 8 inches	$\frac{5}{16}$ "
From 8 inches upwards	$\frac{3}{8}$ "

The holes are usually made round, but from the pliability of the lace, which enables it to adapt itself to the form of the hole to a remarkable degree, it is not unusual to preserve the strength of a belt by making an oblong hole, as in Fig. 2683 at A, or a mere slit, as at B, which, from removing less material from the belt, leaves it to that extent stronger.

The ends of the belt should be cut quite square, and at a right angle to the edges, so that when the two ends are drawn together by the lace the edges of the belt will remain straight, and not curved, as they would do if either end of the belt were not cut at a right angle. Suppose, for example, that the ends of a belt were cut aslant, as in Fig. 2684, when laced up the edge of the belt would come as in Fig. 2685.

The holes must be punched exactly opposite to each other, or lacing the belt will bring the edges out of fair, as shown in Fig. 2686, the tension of the lace drawing the holes opposite to each other, irrespective of where the edges of the belt will come. If

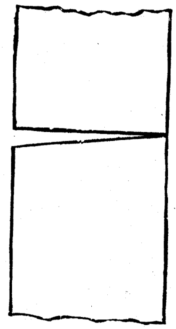


Fig. 2684.

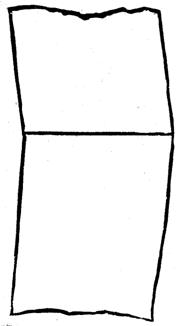


Fig. 2685.

some of the holes are opposite and others are not, the latter will throw the edges of the belt out of line to some extent, especially if the lace is first entered in the holes that are not opposite, because, in that case, drawing the lace tight at once throws the belt edges out, and the subsequent lacing has but a limited effect in correcting the error, unless, indeed, the majority of the holes are opposite, and but one or two are out of line.

The lace should be drawn sufficiently tight to bring the ends of the belt firmly together, and should be laced with an even tension throughout, and for a belt doing heavy duty should have its ends tied in a knot at the back, and in the middle of the belt.

The width of the lace is usually about as follows :—

Width of Belt.	Width of Lace.
24 inches and over	$\frac{1}{2}$ inch
6 to 24 inches	$\frac{3}{8}$,,
2 to 4 inches	$\frac{5}{16}$,,
2 inches and less	$\frac{1}{4}$,,

Since belts are tightened by cutting a piece off one end (preferably the end which shows the holes most stretched), it is obvious that a butt-joint possesses an advantage, because as less of the belt length is occupied by the holes they may be cut quite out and

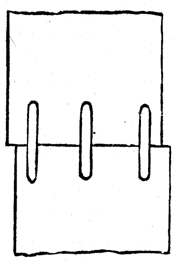


Fig. 2686.

new ones punched, whereas, in some cases, the length of the belt occupied by the holes in a lap-joint is more than the length of belt required to be cut out to tighten it.

There are many different methods of lacing a belt, but those here described are generally preferred. Thus referring to Fig. 2687 the lace is first passed through holes G and D, the ends being of equal length from the belt and emerging on the side that is to be the outside of the belt, thence each end of the lace is laced towards the edge of the belt, the dotted lines in the cut showing the path of the lace. It is then laced back to the middle of the belt, the second inside lacing exactly overlaying the first, the laces never crossing; the outside appearing as in Fig. 2688. The ends are in some cases tied in a knot on the outside, and in others fastened as shown in Fig. 2689, in which case the ends are merely held by friction, which will serve very well unless for a belt that is tightly strained.

By this method of lacing all the crossing of the lace is on the outside of the belt, which is an advantage, because from the creep

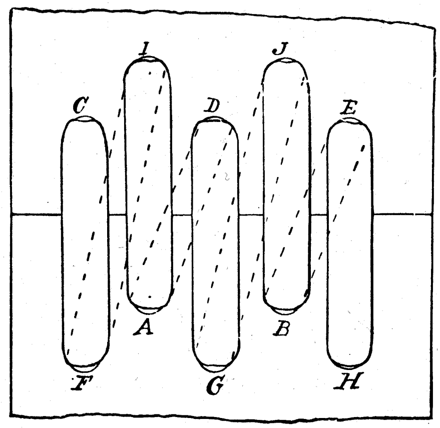


Fig. 2687.

of the belt the lace undergoes considerable friction, which is apt to rapidly wear out the lace, especially if it be crossed on the side of the bed that meets the pulley surface.

Fig. 2690 shows a method of lacing in which the crossing of the

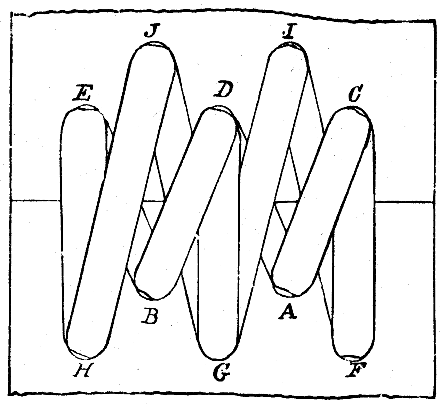


Fig. 2688.

lace is entirely avoided, the knot being on the outside at *a a*. The path of the lace on one side of the belt is shown in full lines, and on the other side in dotted lines.

The objections to lacing are that the lace lifts the belt from the

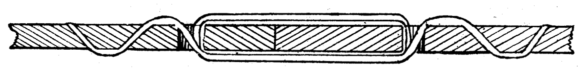


Fig. 2689.

pulley surface, which throws all the wear on the lace, causing it eventually to break, and which also reduces the area of belt (at the joint) in contact with the pulley surface and reduces the driv-

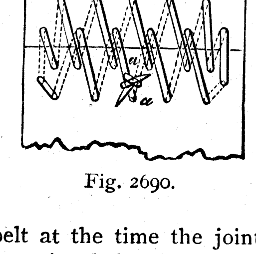


Fig. 2690.

ing power of the belt at the time the joint is passing over the pulley. In fact, in running belts this reduction of transmitting capacity is not great, because of the rapidity with which the joint passes over the pulley, but in slow moving belts slip is very apt to occur when the lace meets the pulley, especially if the power transmitted is great in proportion to the width of the belt.

There are considerable movement and friction between the lace and the belt, more especially when the latter passes over a pulley of small diameter, and this with the friction due to whatever amount of slip the belt may experience, wears away the lace so that in time it breaks. Sometimes a cover is employed as shown

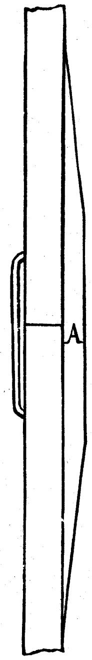


Fig. 2691.

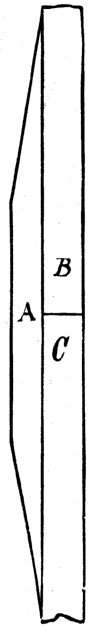


Fig. 2692.

in Fig. 2691 at A, to protect the lace, the cover being riveted or cemented to the belt on the side that is to meet the pulley surface. A similar means is also sometimes employed to make a butt joint. Thus in Fig. 2692 A is the cover riveted or cemented to the two ends B C, of the belt so as to dispense with lacing.

Fig. 2693 represents an excellent method of joining very thin belts, the operation being as follows :—

Place the two ends of the belt together with the edges fair one

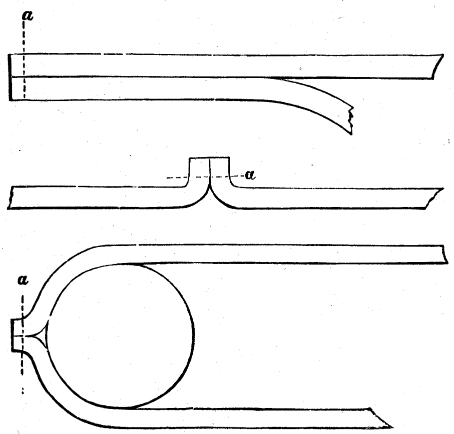


Fig. 2693.

with the other, and with an awl make a row of holes at *a*, through both ends ; then take about half a yard of strong twine (in some cases a lace or gut is better) and draw half the length through the first hole, then pass each end of the twine through the second hole, one end to the right and the other to the left, and draw both tight at the same time, and so on until the last hole is reached, when one end only of the twine is passed through ; the two ends of the twine are then knotted tight together and the excess cut off.

The middle sketch shows the joint when the belt is stretched. The lower sketch shows it passing over a small pulley, where it will be seen that in the act of bending over the curve there is no friction between the lace and the belt, and this is the reason of its superiority over other methods, where there is always more or less friction between the lace and the belt when bending over a curve. Another advantage is, that in this system the lace does not come into contact with the pulley, so that whatever friction or slipping may take place between the belt and the pulley, the lacing is perfectly unaffected by it.

A lap joint is one in which the two ends of the belt overlap, as in Fig. 2694. The overlap is cut down to a plain bevel so as to reduce the joint to nearly or quite the same thickness as the main body of the belt. The lap joint is employed to join together the strips of leather forming the belt, and to fasten the ends of the finished belt together. In making the belt the overlap is cemented and riveted, while in joining the ends it may be cemented, or riveted, or laced.

The advantage of rivets lies simply in that they are easily applied. Their disadvantages are that they grip but a small area of the belt, namely, that portion beneath the rivet head and washer surface ; hence, when rivets are used the joint should always be cemented also. A more important defect is, however,

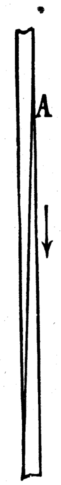


Fig. 2694.

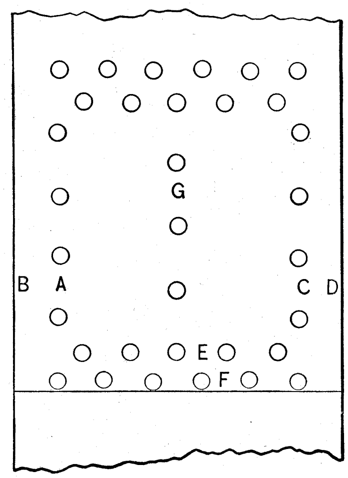


Fig 2695.

that the heat generated by the compression of the rivet while riveting it is sufficiently great to *burn the leather* beneath the rivet-head. The reason that the leather under the head and not under the washer or burr at the riveted end of the rivet burns is, that although the heat due to riveting is most at the burr end of the rivet, its passage from the rivet to the washer is less rapid than it is through the body of the rivet, because in the one case it has to be transferred from one body to another (from the rivet to the burr), while in the other its passage is uninterrupted and continuous.

Rivets for lap joints are usually placed about, as in Fig. 2695, the rows A and C being about $\frac{1}{2}$ inch from the edges B and D respectively, and the row F about $\frac{3}{8}$ inch from the edge F of the lap, while the rivets are about $\frac{5}{8}$ inch apart in the rows.

For comparatively narrow belts as, say, four inches wide, a single row G would be placed in the middle, additional middle rows should for wider belts be about $1\frac{1}{4}$ inches apart.

The rivet holes should be a close fit to the rivets, the latter being left just long enough to hold the washer or burr and sink with it, in the riveting, to the level surface of the belt.

The heads of the rivets should be on the side of the belt that is to run next to the pulley.

The strongest method of forming a belt is by means of small taper wooden pegs, such as are used in boot and shoe manufacture, the joint being cemented, and the pegs inserted. In this case the belt is merely pierced with an awl, hence none of the leather is removed.

The arrangement of wooden pegs should be as in Fig. 2696, the rows A and B being respectively about $\frac{5}{8}$ inch from the edges C D, the row E being about $\frac{1}{4}$ inch from the edge of the joint, and H about $\frac{3}{4}$ inch from that edge. The pegs are placed about $\frac{1}{2}$ inch apart in the rows.

A cemented and pegged joint is the strongest made, and it preserves a more equal tension throughout the belt than any other,

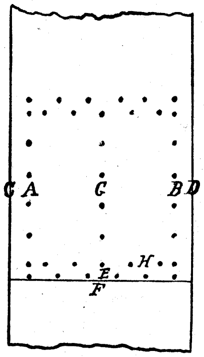


Fig. 2696.

while the belt is strong, since the hole for the pegs may be pierced with an awl, which does not remove any leather from the belt, as is the case with punched holes.

The length of the lap in some of the best practice is as follows:

When the strips of leather are cut from the hide in such lengths that the part termed the shoulder of the hide is utilised, a uniform lap of 8 inches is employed for all widths of belt. When the strips do not contain the shoulder of the hide, the following are the respective lengths of lap:—

Width of single belt.	Length of lap.
1 to $4\frac{1}{2}$ inches	$4\frac{1}{4}$ inches.
5 inches	5 ,,
6 to 8 inches	6 ,,
9 inches	$6\frac{1}{2}$,,
10 to 14 inches	7 ,,
15 to 24 ,,	8 ,,

All double belts are given a 6-inch lap.

Another and excellent method of joining a belt, or of fastening two thicknesses together to form a double belt, is to sew it together with lace leather, as shown in Fig. 2697. The lace is in this case

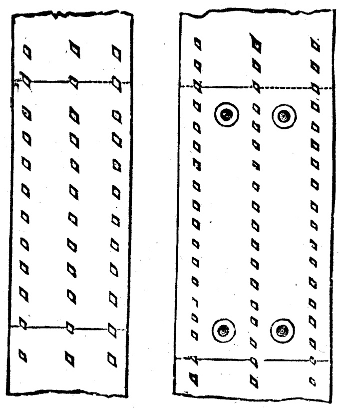


Fig. 2697.

about $\frac{1}{4}$ inch wide, the holes being pierced so as to have the lace diagonal, as shown in the cut. Sometimes four rivets are added at the joint as shown in the cut.

Other methods of fastening the ends of leather belts are by means of metal hooks of various forms. Fig. 2698 represents a fastening of this kind, the appearance of both sides of the joint being shown in the figure. In this case considerable leather is removed from the belt, but this is to some extent compensated for, because the hook holds each end of the belt in two places; that is to say, in the crook of the hook as well as at the end. This, however, while it has the effect of increasing the grip of the hook on the belt, still leaves the belt as a whole weaker, by reason of the removal of leather to form the holes.

In Figs. 2699 and 2700 is shown a belt screw, intended to take the place of rivets, and thus avoid the burning of the leather which accompanies the use of rivets. It consists of two screws, one having a right and the other a left-hand thread. The former is of bronze, and has a coarse exterior thread cut conically, while it is

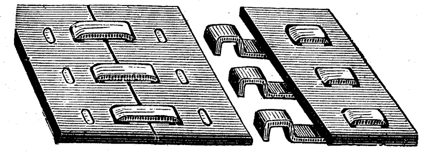


Fig. 2698.

hollow with a fine thread tapped inside. The latter is of steel, and has a conical shoulder underneath. The heads of both screws are slightly rounded and formed with circular grooves on the under side, to give them a firm grip on the leather. The conical screw is first run into the leather, and the steel screw is then introduced. The belt is run with the head of the latter on the inner side.

If the body of a narrow belt is riveted it contains two rows only of rivets; but as the width of the belt increases, other rows are introduced, all the rows running the entire length of the belt. In

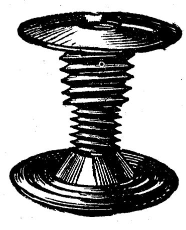


Fig. 2699.

some cases two separate single belts running one over or outside the other are employed in place of an ordinary double belt, and the arrangement works well.

Two single belts applied in this manner are especially preferable to a double belt when used upon a small pulley, because they will bend to the curvature of the pulley more readily, being more pliable; whereas a double belt will from its resistance to bending not envelop as much of the circumference of the belt as is due to the relative sizes of the pulleys, and the distance apart of their axes.

Round leather belts are made in two forms, the solid and the twisted. The first consists of a simple leather cord, hence its

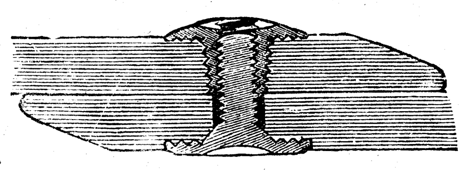


Fig. 2700.

diameter cannot exceed the thickness of the leather. The second consists of a strip of leather twisted into cylindrical form, the grain side of the leather being outside.

The ends of round belts are usually joined by means of cylindrical hooks and eyes, which are threaded so as to screw on to the end of the belt, but for twisted round belts it is better to place in the centre of the belt a small core of soft wood. The ends of the belt should be slightly tapered, and the hook and eye screwed firmly home. Sometimes from the smallness of the pulleys the inflexibility of the hook and eye becomes objectionable, and a simple hook is employed on solid round belting.

The length of twisted round belting may be altered by twisting or untwisting it, which renders it unnecessary to cut the belt for a small amount of shortening.

Round belts should bear upon the sides, and not on the bottom of the pulley-groove, which increases their transmitting power. Thus, if the groove is a semicircle of the same radius as is the belt when new, the stretch of the belt as it wears decreasing its diameter, it will then touch only on the bottom of the groove. Furthermore, when the belt bears on the sides only of the groove it becomes wedged to a certain extent in the sides of the pulley groove.

V-belting is formed of strips of leather welted together, as shown in Figs. 2701 and 2702, the latter showing the joint or splice of the belt. The pulleys are **V**-grooved as shown. The tension

bend edgeways, as denoted by the dotted line *b*, which it does to some extent, carrying the belt with it.

CHANGING OR SLIPPING BELTS ON PULLEYS.—To change a belt on a stepped cone, proceed as follows :—

Suppose the belt to be on the small step of the driving cone, and to require to run on the largest step. Throw the belt on the smallest step of the lower cone and place the palm of the hand on the inside face of the belt on the side on which it approaches that cone. Draw the belt tight enough (with the palm of the right hand) to take up the slack and cause the lower cone to rotate. When it is in full motion place the palm of the left hand against the inside face of the other side of the belt (while still keeping the pressure of the right hand against the slack side of the belt).

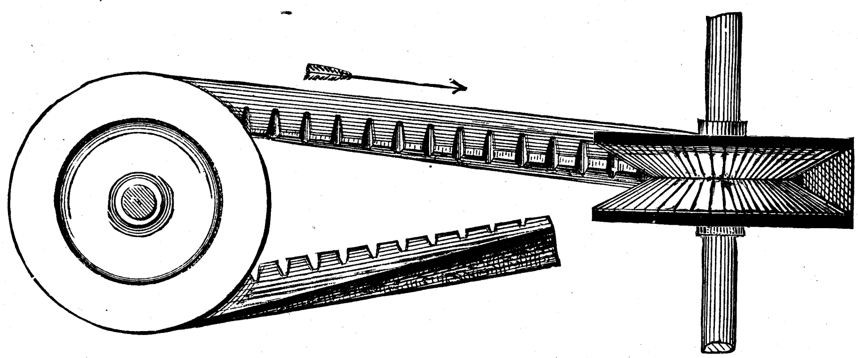


Fig. 2701.

of the belt causes it to grip the sides of the groove on the wedge principle, and the belt is flat at the apex of the **V** so that it shall not bottom in the groove, which would impair its wedging action. This class of belt is largely employed for connecting shafts at an angle, especially in cases where the distance between the shafts is small, in which case it will last much longer than a flat belt.

From the construction, the rivets joining the pieces forming the belt do not come into contact with the surfaces of the pulley, and

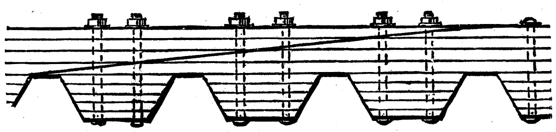


Fig. 2702.

from the tension of the belt causing it to wedge into the sides of the pulley groove, the driving power is greater than that simply due to the area of contact and the tension of the belt.

A belt will run to the largest diameter of a pulley, thus in Fig. 2703, the belt would, unless guided, gradually creep up to the side A of pulley P, and following this action would move to side C of pulley D.

If the pulleys are parallel, but the axis of their shafts are not in line, then the belt will run towards that side on which the axes are

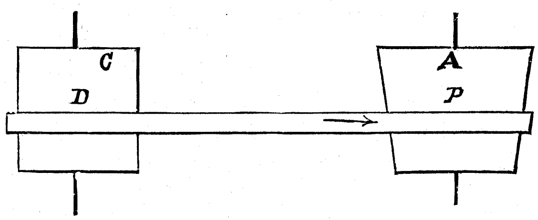


Fig. 2703.

closest; thus in Fig. 2704 the belt would run towards the side P of the large pulley, because the belt B will meet the pulley surface at *a*, and if a point on the belt at *b* travelled coincident with the point on the pulley with which it took contact, its plane of rotation, while on the pulley, would be as denoted by the dotted line *b*.

But to follow this plane of rotation, the belt would require to

Release suddenly the pressure of the right hand and immediately with a quick and forcible lateral motion of the left hand force the belt towards the larger step of the upper cone, which will cause it to mount the next step, when the operation may be repeated for each succeeding step.

If the steps of the cone are too steep, or the belt is too long for this method, a wooden rod may be used, its end being applied to the side of the belt that runs on the upper cone and close to the cone. Then lift the belt with the rod, while the lower end of the rod is inclined away from the step the belt is to mount, when the belt will mount the step of the rotating cone.

In the case of broad heavy belts it is best to stop the running pulley and place the belt on it, then lift the belt edge on the stationary pulley at the point where the belt will first meet it

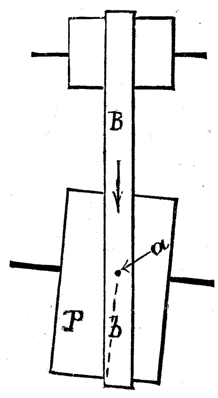


Fig. 2704.

when in motion, forcing the belt on by hand as far as possible. Take a strong cord, as, say $\frac{3}{8}$ inch diameter, and double it, pass the loop between the pulley arms around the belt and over the pulley face. Pass the two free ends of the cord through the loop (formed by doubling the cord) and pull the free ends as tight as possible by hand. While standing on the side of the pulley opposite to that of the belt, communicate slow motion to the driving pulley and release the ends of the cords as soon as the belt is on. The belt, in travelling from the pulley, will then undo the cord of itself.

A belt may be taken off a pulley, either by pressing it in the required direction and as close to the pulley as possible, or by holding the two sides of the belt together, which should be done as far from the running pulley as possible, or as far from the pulley the belt is required to come off as possible.

In Fig 2705 is shown a device for automatically replacing a belt that has slipped off a pulley. A is the pulley and B the device, which has a curved projection which is of the full width of the device at one end, where it comes even with the perimeter of A, and tapers laterally towards the outside edge of the device. As a result the belt will easily pass on the broad end and cause the device to rotate, the belt running up the curved projection and therefore lifting clear of the pulley A, but on account of the taper of the projection the belt finally has contact with the projection on one edge only, and therefore tips over to the other side, and as a result falls on A, because it is under tension and naturally adjusts itself to be in line with the pulley at the other end of the belt. It would appear that the belt, if running, would move on the pulley, driving it, and this would be the case if sufficient time were allowed for it to do so, but the action of the device is too quick, and furthermore, when the belt is off one pulley and therefore loose its motion is apt to become greatly reduced, which retards its moving laterally on the pulley driving it.

It is obvious that the device must be applied to that side of the pulley on which the belt is found to run off, but it may be noted that belts are not apt to run off the loose pulley, but off the driving one, and only at times when from excessive resistance or duty the velocity of the pulley is reduced below that of the belt, or the velocity of the belt is less than that of the pulley driving it;

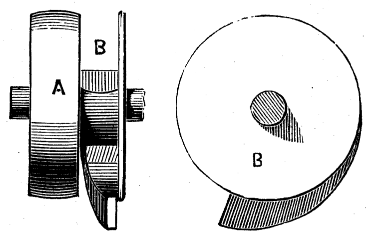


Fig. 2705.

hence the device must be applied on the outside of the fast or tight pulley.

The driving power of a belt is determined principally by the amount of its pull upon the pulley, and the speed at which it travels.

The amount of pull is determined by its tension, or in other words, the degree with which it grips the pulley and the closeness with which it lies to the pulley surface. The amount of tension a single belt is capable of withstanding with a due regard to its durability has been fixed by various experimenters at $66\frac{2}{3}$ lbs. per inch of its width. The pull of the belt under this degree of tension will vary as follows:—

It will be more with the grain or smooth side than it will with the flesh or fibrous side of the belt in contact with the pulley face, some authorities stating the amount of difference to be about 20 per cent. It will be more with a smooth and polished surface on the pulley than with one less smooth and polished. At high speeds it will be diminished by the interposition of air between the belt and pulley surface, and from the centrifugal force generated by the passage of the belt around the pulley. It will be more when the pulley is covered with leather rubber or other cushioning substance than when the pulley is bare, even though it be highly polished, some authorities stating this difference to be about 20 per cent.

It will be increased in proportion as the belt envelops a greater proportion of the pulley circumference, the part of the pulley enveloped by the belt when the pulley is at rest (or what is the same thing, at any point of time when it is in motion) being termed the arc of contact.

It is obvious that the arc of contact taken to calculate the belt power must be the least that exists on either the driving or the driven pulley, because when the belt slips it ceases to transmit the full amount of the power it receives, the remainder being expended in the friction caused by the belt slipping over the pulley.

The speed at which a belt may run is limited only by reason of the centrifugal force generated during its passage around the pulley, this force tending to diminish its pressure upon the pulley. The maximum of speed at which it is considered advisable to run a belt is about 6,000 feet per minute; but the amount of centrifugal force generated at this speed depends upon the diameter of the pulley, because the centrifugal force increases in direct proportion as the number of revolutions is increased, or in other words it increases in the same proportion as the velocity; but in a given circle it increases as the square of the velocity. Suppose, then, that it be required to double the velocity of a belt, and that the same pulley be used running at twice the velocity, this will increase fourfold the centrifugal force generated; but if the diameter of the pulley be doubled the centrifugal force generated will be simply doubled; hence it appears that the larger the pulley the less the centrifugal force of the belt in proportion to its velocity. This will be apparent when it is considered that the larger the pulley the nearer will the curve of its circumference approach to a straight line.

The following experiments on the transmission of power by belting were made Messrs. Wm. Sellers & Co.

* These experiments were undertaken with a view to determine, under actual working conditions, the internal resistances to be overcome, the percentage of slip, and the coefficient of friction on belt surface. They were conducted, during the spring of 1885, under the direction of Mr. J. Sellers Bancroft.

These experiments seemed to show that the principal resistance to straight belts was journal friction, except at very high speeds, when the resistance of the air began to be felt. The resistance from stiffness of belt was not apparent, and no marked difference could be detected in the power required to run a wide double belt or a narrow light one for the same tension at moderate speeds. With crossed and quarter-twist belts the friction of the belt upon itself or upon the pulley in leaving it was frequently an item of more importance, as was shown by special experiments for that purpose.

In connection with the experiments upon internal resistances, some interesting points were noted. Changes in tension were made while the belt was running, commencing with a very slack belt and increasing by definite amounts to the working strength. As this point was approached, it was found necessary, to maintain a constant tension, that the tightening bolt should be constantly operated on account of stretch in the belt. Then, again, as the tension was reduced from this limit, it was found that at lower tensions the belt would begin to shrink and tighten for a fixed position of the sliding frame. This stretching and tightening would continue for a long time, the tightening being, of course, limited, but the stretching indefinite and unlimited.

The first series of experiments was made upon paper-coated pulleys 20″ diameter, which carried an old $5\frac{1}{2}''$ open belt $\frac{3}{16}''$ to $\frac{1}{4}''$ thick and 34 ft. long, weighing 16 lbs. The arc of contact on the pulleys has been calculated approximately from the tension on slack side, and for this purpose the width and length of the belt were taken. The percentage of slip must be considered as equally divided between the two pulleys, and from observations made it is easy to calculate the velocity of sliding when the speed is given.

Some of the most important results obtained with this belt are given in Table I. in which the experiments have been selected to avoid unnecessary repetition. In all cases the coefficient of friction is shown to increase with the percentage of slip. The adhesion on the paper-covered pulleys appears to be greater than on the cast-iron surfaces, but this difference may possibly have been due to some change in the condition of the belt surfaces.

After a fresh application of the belt dressing known as "Beltilene," the results obtained are even higher on cast iron than on

* From a paper read before the American Society of Mechanical Engineers by Wilfred Lewis.

paper surfaces, but after a time it was found that the adhesive property of this substance became sensibly less and less. Flakes of a tarry nature rolled up from the belt surface and deposited themselves on the pulleys, or scaled off.

So much was found to depend upon the condition of the belt surface and the nature of the dressing used, that the necessity was felt for experiments upon some standard condition which could be easily realized and maintained. For this purpose a belt was taken from a planing machine when it had become perfectly dried by friction. The results of experiments upon this belt are given in Table II. When dry, as used on the planer, the coefficients for any given percentage of slip were much smaller than those given in Table I. This was naturally to be expected, and

TABLE I.

STRAIGHT OPEN BELT $5\frac{1}{2}''$ WIDE BY $\frac{7}{32}''$ THICK AND 34 FT. LONG, WEIGHING 16 LBS., IN GOOD PLIABLE CONDITION, WITH HAIR SIDE ON PULLEYS 20 IN. DIAM. RUNNING AT 160 R. P. M., OR ABOUT 800 FT. PER MINUTE.

No. of Experi'nt.	Sum of Tensions. $T+t$ Initial.	Working.	Final.	* $T-t$ Working.	* T	* t	* $\frac{T}{t}$	Percentage of Slip.	Velocity of Slip in ft. per minute.	Arc of Contact.	Coefficient of Friction.	Remarks.
17	200	210		100	155	55	2.82	.4	1.6	177°	.336	Paper-covered pulleys.
19		220		140	180	40	4.50	.6	2.4	176	490	
21		246		180	213	33	6.45	1.2	4.8	175	.610	
22		260		200	230	30	7.67	2.6	10.4	174	.671	
23		270	180	220	245	25	9.80	7.9	31.6	173	.756	
24	300	316		200	258	58	4.45	.7	2.8	177	.483	
27		344		260	302	42	7.20	1.0	4	176	.643	
28		350		280	315	35	9	1.8	7.2	175	.719	
29		364		300	332	32	10.4	2.8	11.2	175	.784	
30		380	260	320	350	30	11.7	5.5	22	175	.805	
31	400	422		200	211	111	1.90	.5	2	179	.205	
33		440		280	360	80	4.50	.8	3.2	178	.484	
35		470		360	415	55	7.54	1.1	4.4	177	654	
36		506		400	453	53	8.54	2.1	8.4	177	.694	
37		520	380	420	470	50	9.40	5	20	177	.725	
60	200	205		80	147.5	67.5	2.18	.5	2	178	.251	Cast-iron surfaces.
61		210		100	155	55	2.82	.9	3.6	177	.336	
62		215		120	167.5	47.5	3.52	1.7	6.8	177	.407	
63		220		140	180	40	4.50	3	12	176	.490	
65		246	180	180	213	33	6.45	12	48	175	.610	
66	300	300		120	210	90	2.33	.5	2	179	.270	
68		310		160	235	75	3.13	.8	3.2	179	.365	
69		315		180	247.5	67.5	3.67	1	4	178	.418	
70		320		200	260	60	4.33	1.7	6.8	178	.472	
71		325		220	272.5	52.5	5.19	2.6	10.4	177	.545	
72		340		240	290	50	5.80	3.8	15.2	177	.569	
73		350		260	305	45	6.77	5.5	22	176	.623	
74		360		280	320	40	8	8.6	34.4	176	.677	
75		375		300	337.5	37.5	9	15.2	60.8	175	.719	
76	400	420		200	31c	110	2.82	.6	2.4	179	.336	Belt dressed with "Beltilene."
78		460		280	370	90	4.11	1	4	179	.452	
81		480		340	410	70	5.86	1.5	6	178	.569	
84		510		400	455	55	8.27	2.2	8.8	177	.684	
86		535		440	487.5	47.5	10.2	4.5	18	177	.760	
88		560	385	480	520	40	13	8.4	33.6	176	.834	
89	300	320		120	220	100	2.20	.4	1.6	179	.252	
93		350		200	275	75	3.67	.8	3.2	178	.418	
97		390		280	335	55	6	1.6	6.4	177	.580	
101		440		360	400	40	10	3.1	12.4	176	.750	
104		470	310	420	445	25	17.8	8.6	34.4	173	.953	

* T represents the tension on the tight part, and t on the sag part of the belt.

the experiments were continued to note the effect of a belt dressing in common use, known as "Sankey's Life of Leather," which was applied to the belt while running. At first, the adhesion was very much diminished, but it gradually increased as the lubricant became absorbed by the leather, and in a short time the coefficient of friction had reached the unprecedented figures of 1.44 and 1.37.

An interesting feature of these and subsequent experiments is the progressive increase in the sum of the belt tensions during an increase in load. This is contrary to the generally accepted theory that the sum of the tensions is constant, but it may be accounted for to a large extent by the horizontal position of the belt, which permitted the tension on the slack side to be kept up by the sag. That this is only a partial explanation of the phenomenon, and that the sum of the tensions actually increases as their difference increases for even a vertical position of the belt, will be shown by a special set of experiments. If a belt be suspended vertically, and stretched by uniformly increasing weights, it will also be found that the extension is not uniform, but diminishes as the load is increased, or, as already stated, the stress increases faster than the extension. A little reflection will show that when this is the case the tensions must necessarily increase with the load transmitted.

TABLE II.

DOUBLE BELT $2\frac{1}{4}''$ WIDE BY $\frac{5}{16}''$ THICK, AND 32 FT. LONG, WEIGHING $9\frac{1}{2}$ LBS., ON 20" CAST-IRON PULLEYS. THIS BELT HAD BEEN USED ON A PLANING MACHINE, WAS QUITE PLIABLE, DRY, AND CLEAN. 160 R. P. M.

No. of Experi'nt.	Sum of Tensions. $T+t$ Initial.	Working.	Final.	$T-t$ Working.	T	t	$\frac{T}{t}$	Percentage of Slip.	Velocity of Slip in ft. per min.	Arc of Contact.	Coefficient of Friction.	Remarks.
105	100	104		40	72	32	2.25	.3	1.2	177°	.263	
106		110		60	85	25	3.40	.8	3.2	177	.395	
107		122		80	101	21	4.81	1.7	6.8	176	.511	
108		138		100	119	19	6.26	4.3	17.2	175	.600	
109	200	208		80	144	64	2.25	.4	1.6	179	.260	
110		212		100	156	56	2.81	.7	2.8	179	.331	
111		216		120	168	48	3.50	1	4	179	.401	
112		220		140	180	40	4.50	1.8	7.2	178	.484	
113		230		160	195	35	5.57	4.4	17.6	178	.553	
114	300	308		120	214	94	2.28	.4	1.6	180	.262	
116		316		160	238	78	3.05	.8	3.2	180	.355	
118		322		200	261	61	4.28	1.6	6.4	179	.465	
119		330	285	220	275	55	5	2.6	10.4	179	.516	
121	400	404		160	282	122	2.31	.7	2.8	180	.267	
124		410		220	315	95	3.37	1.5	6	180	.387	
125		412		240	326	86	3.79	2.3	9.2	180	.424	
126		414		260	338	78	4.33	3.7	14.8	179	.469	
127		416	370	280	348	68	5.12	10.1	40.4	179	.523	Belt almost slipped off.
128	500	516		200	358	158	2.27	.5	2	180	.261	
131		520		260	390	130	3	1.1	4.4	180	.350	
133		525		300	412.5	112.5	3.67	1.8	7.2	180	.414	
134		525		320	422.5	102.5	4.11	2.7	10.8	180	.450	
135		525	460	340	432.5	92.5	4.67	5.1	20.4	180	.490	
136	100	105		40	72.5	32.5	2.02	.2	.8	177	.228	Here the belt was coated with "Sankey's Life of Leather," and run until in good working condition before noting experiments.
137		110		60	85	25	3.40	.4	1.6	177	.396	
138		125		80	102.5	22.5	4.56	.6	2.4	176	.494	
140		150		120	135	15	9	1.8	7.2	174	.723	
141		164		140	152	12	12.7	2.8	10.8	172	.779	
142		180		160	170	10	17	5	20	170	.954	
144		215		200	207.5	7.5	27.7	7.3	29.2	166	1.15	
146		250		240	245	5	49	10.6	42.4	158	1.41	
147		270	90	260	265	5	53	17.7	70.8	158	1.44	
149	100	105		40	72.5	32.5	2.02	.2	.8	177	.228	Three days later without any additional dressing.
150		110		60	85	25	3.40	.3	1.2	177	.396	
151		120		80	100	20	5	.4	1.6	176	.524	
153		150		120	135	15	9	.7	2.8	174	.723	
155		182		160	171	11	15.5	1.2	4.8	172	.913	
156		202		180	191	11	17.3	3	12	172	.950	
157		216		200	208	8	26	5.8	23.2	167	1.12	
158		232		220	226	6	37.3	7	28	161	1.29	
159		252		240	246	6	41	9.8	39.2	161	1.32	
161		292		280	286	6	47.7	13.7	54.8	161	1.37	

A piece of belting 1 sq. in. in section and 92 ins. long was found by experiment to elongate $\frac{1}{4}$ in. when the load was increased from 100 to 150 lbs., and only $\frac{1}{8}$ in. when the load was increased from 450 to 500 lbs. The total elongation from 50 to 500 lbs. was $1\frac{11}{16}''$, but this would vary with the time of suspension, and the measurements here given were taken as soon as possible after applying the loads. In a running belt the load is applied and removed alternately for short intervals of time, depending upon the length and speed of the belt, and the time for stretching would seldom be as great as that consumed in making the experiments just mentioned.

The differences between the initial and final tensions unloaded, as given in the tables, show the effect of extension or contraction during the course of the experiments made at a fixed position of the pulleys. The percentage of elongation which a belt undergoes in passing from its loose to its tight side, is the measure of the slip which must necessarily take place in the transmission of power. This is a direct loss, and within the assumed working strength of 500 lbs. per sq. in. for cemented belts without lacings, experiment indicates that it should not exceed $1\frac{1}{2}$ or 2 per cent. When, therefore, an experiment shows less than 2 per cent. of slip, the amount may be considered as allowable and proper, and the belt may be relied upon to work continuously at the figures given.

Table III. gives the results of experiments upon a soft and pliable rawhide belt made by the Springfield Glue and Emery Co. This belt had been used by the Midvale Steel Co. for a period of seven months, at its full capacity, and was sent in its usual working condition to be tested. It had been cleaned and dressed with castor oil at intervals of three months, and was received three weeks after the last dressing. Commencing with the light initial tension of 50 lbs. on a side, it was found impossible with the power at command to reach a limit to the pulling power of the belt, and in order to do so the experiment was made of supporting the slack side of the belt upon a board to prevent sagging.

These experiments, however, are subject to an error arising from the friction of the belt upon the board, the amount of which was not determined. All of the experiments, in fact, are subject to slight errors which were extremely difficult to eliminate or properly allow for, but an effort has been made throughout to obtain results which should approximate as closely as possible to the truth. The sum of the tensions, as determined by measuring scales, was subject only to errors in observation. This part of the apparatus was carefully tested by a horizontal pull of known amount and made to register correctly.

The difference of the tensions $T-t$, as computed from the reading of the scales, was measured by the force of an equivalent moment at 20″ radius. This moment, divided by the radius of the pulley was taken to be the difference $T-t$.

In this calculation, it will be noticed that two slight corrections have been omitted which are opposite in effect and about equal in degree. One is the friction of the brake shaft in its bearings, which of course was not recorded on the scales, and the other is the thickness of the belt which naturally increases the effective radius of the pulley. Both of these errors are somewhat indefinite, but the correctness of the results obtained was tested in a number of cases by the sag of the belt, and the tension t, as calculated from the sag, was found to agree closely with the tension calculated by the adopted method.

As the limiting capacity of the belt was reached, the difficulty of obtaining simultaneous and accurate observations was increased by the vibrations of the scale beams. This was apparently due to irregularity in the slip, and it was only by the use of heavily loaded beams and a dash-pot that readings could then be taken at all. The dash-pot consisted of a large flat plate suspended freely in a bucket of water by a fine wire from the scale beam. This provision, however, was applied only to the scales on which the vibrations were more pronounced.

A peculiar and important feature of Tables III. and IV. is the

TABLE III.

RAWHIDE BELT 4″ WIDE BY $\frac{9}{32}$″ THICK AND 31 FT. LONG, WEIGHING 15 LBS. 160 R. P. M. ON 20″ CAST-IRON PULLEYS.

No. of Experi'nt.	Sum of Tensions. $T+t$ Initial.	Working.	Final.	$T-t$ Working.	T	t	$\frac{T}{t}$	Percentage of Slip.	Velocity of Slip in ft. per min.	Arc of Contact.	Coefficient of Friction.	Duration of run at time of experiment.	Remarks.
171	100	118		40	79	39	2.03	.2	.8	1778	.229		
173		140		80	110	30	3.67	.4	1.6	176	.423		
175		168		120	144	24	6	.6	2.4	174	.590		
177		202		160	181	21	8.62	.8	3.2	172	.661		
179		232		200	216	16	13.5	1	4	170	.897		
181		268		240	254	14	18.1	1.2	4.8	167	.993		
183		302		280	291	11	26.5	1.4	5.6	163	1.15		
184		318	110	300	309	9	34.3	1.6	6.4	160	1.27		
185	100	150	115	140	145	5	29	1.6	6.4	180	1.02		Slack side of belt running on a board to prevent sagging.
186	200	258		240	249	9	27.4	1.2	4.8	180	1.05		
188		290		280	285	5	57	2.2	8.8	180	1.29		
189	300	412		400	406	6	67.7	1.7	6.8	180	1.34		
190		428		420	424	4	106	1.8	7.2	180	1.48		
191		446	275	440	443	3	148	3.3	13.2	180	1.59		
192	400	570	360	560	565	5	113	2	8	180	1.47		
329	100	110		40	75	35	2.14	.3	.6	177	.246		10″ cast-iron pulleys.
330		135		80	107.5	27.5	3.90	.6	1.2	175	.446		
331		198		160	179	19	9.42	1	2	171	.751		
332		275		240	257.5	17.5	14.7	1.5	3	169	.911		
334		345		320	232.5	12.5	18.6	2	4	165	1.01		
336		420	110	400	410	10	41	3.2	6.4	162	1.31		
339	200	230		160	195	35	5.86	.8	1.6	176	.576		
340		360		320	340	20	17	1.6	3.2	171	.949		
341		435		400	417.5	17.5	23.8	2	4	169	1.07		
342		505		480	492.5	12.5	39.4	2.7	5.4	165	1.28		
343		590	200	560	575	15	38.3	5	10	168	1.24		
344	300	400		320	360	40	9	1.4	2.8	175	.719		
345		450		400	425	25	17	1.7	3.4	173	.938		
346		520		480	500	20	25	2.1	4.2	171	1.08		
347		600		560	570	10	57	3	6	162	1.43	1 min.	
348		600	280	560	570	10	57	3.4	6.8	162	1.43	5 min.	
350	400	500		400	450	50	9	1.6	3.2	176	.715		
351		550		480	515	35	14.7	1.8	3.6	175	.880		
352		605		560	577.5	17.5	21.3	2.3	4.6	169	1.04		
353		680		640	660	20	33	3.2	6.4	171	1.17	1 min.	
354		680		640	660	20	33	3.7	7.4	171	1.17	5 min.	
355		680		640	660	20	33	4.1	8.2	171	1.17	10 min.	[4 m. later.
356		680		640	660	20	33	6.1	12.2	171	1.17	15 min.	Belt slipped off
357		600		560	580	20	29	10	20	171	1.13	20 min.	Continuing.
358		600		560	580	20	29	17.2	34.4	171	1.13	25 min.	
359		530		480	505	25	20.2	5.2	10.4	173	.955	30 min.	
360		530	350	480	505	25	20.2	2.8	5.6	173	.955	35 min.	
361	500	570		400	485	85	5.71	1.3	2.6	178	.561		
364		700		640	670	30	22.3	2.3	4.6	174	1.02		
365		755		720	637.5	17.5	36.4	3.2	6.4	169	1.22		
366		820		800	810	10	81	6.6	13.2	162	1.55		Belt slipped off 2 m. later.
367		750		720	735	15	49	5.1	10.2	168	1.32	1 min.	
368		750		720	735	15	49	11	22	168	1.32	5 min.	
369		690		640	665	25	26.6	12	24	173	1.09		Belt slipped off 3 m. later.
370		610		560	585	25	23.4	14.4	28.8	173	1.05	1 min.	
371		610		560	585	25	23.4	20	40	173	1.05	4 min.	
372		550		480	515	35	14.7	7.4	14.8	175	.880	1 min.	
373		550	410	480	515	35	14.7	2.3	4.6	175	.880	5 min.	
374	600	680		480	580	100	5.8	1.5	3	178	.566		
376		755		640	697.5	57.5	12.1	2.1	4.2	177	.807		
378		850		800	825	25	33	2.8	5.6	173	1.16	1 min.	
379		850		800	825	25	33	3.5	7	173	1.16	5 min.	Belt slipped off 5 m. later.
380		780		720	750	30	25	8.8	17.6	174	1.06	1 min.	
381		680		560	620	60	10.3	11.2	22.4	177	.755	5 min.	
382		680		560	620	60	10.3	2	4	177	.755		After running 5 minutes at $T-t=560$.
383		730		640	685	45	15.2	2.5	5	176	.886	1 min.	
384		730		640	685	45	15.2	2.4	4.8	176	.886	5 min.	
385		780		720	750	30	25	4.6	9.2	174	1.06	1 min.	
388		780	550	720	750	30	25	8.8	17.6	174	1.06	5 min.	
389		780		720	750	30	25	4	8	174	1.06	1 min.	Belt scraped.
390		780		720	750	30	25	6.4	12.8	174	1.06	5 min.	Belt slipped off 2 m. later.
391		730		640	685	45	15.2	3.7	7.4	176	.886	1 min.	
392		730	550	640	685	45	15.2	3.9	7.8	176	.886	5 min.	
396	600	680		400	540	140	3.86	2	.45	179	.432		18 r. p. m. 10″ cast-iron pulleys.
397		820		720	770	50	15.4	17.2	3.87	176	.890		
398		750		640	695	55	12.6	15	3.37	177	.874		
399		700		560	630	70	9	9.4	2.17	177	.711		
400		670		480	575	95	6.05	4.5	1.12	178	.579		
401		630	550	400	515	115	4.48	3.5	.75	178	.483		
402		830		720	775	55	14.1	26	5.85	177	.856		
403		630		320	475	155	3.06	1.5	.30	179	.358		
404		610		60	335	275	1.22	.7	.16	180	.063		
408	600	610		120	365	245	1.49	.2	.09	180	.127		20″ cast-iron pulleys. 18 r. p. m.
413		660		400	530	130	4.08	1	.45	179	.450		
415		710		560	635	75	8.46	1.9	.86	177	.691		
416		750		640	695	55	12.6	3.2	1.44	177	.820		
417		800		720	760	40	19	3.8	1.71	175	.964		
418		340		200	274	70	3.91	.6	.27	177	.441		
419	300	380		280	330	50	6.6	1.2	.54	176	.614		
421		450		400	425	25	17	3.2	1.44	173	.938		
423		515		480	497.5	17.5	28.4	4	1.8	169	1.13		
425		580		560	570	10	57	5	2.25	162	1.43		
427		695		680	687.5	7.5	91.7	7	3.15	155	1.67		

TABLE IV.

DOUBLE OAK-TANNED LEATHER BELT 4″ WIDE BY $\frac{5}{16}$″ THICK AND 30 FT. LONG, WEIGHING 17 LBS., ON 10″ CAST-IRON PULLEYS. 160 R. P. M.

No. of Experi'nt.	Sum of Tensions. $T+t$ Initial.	Working.	Final.	$T-t$ Working.	T	t	$\frac{T}{t}$	Percentage of Slip.	Velocity of Slip in ft. per min.	Arc of Contact.	Coefficient of Friction.	Duration of run at time of experiment.	Remarks.
209	120	120		48	84	36	2.33	.4	.8	176°	.275		
210		140		80	110	30	3.67	.6	1.2	175	.426		
211		168		120	144	24	6	.9	1.8	174	.590		
212		198		160	179	19	9.42	1.6	3.2	170	.756		
213		235		200	217.5	17.5	12.4	2.3	4.6	174	.829		
214		270		240	255	15	17	3.2	6.4	168	.966		[dle of belt.
215		310		280	295	15	19.7	5.1	10.2	168	1.02		Sag 10″ at mid-
216		345	122	320	332.5	12.5	25.8	9.4	18.8	164	1.13		Finally slipped off.
217	200	200		48	124	76	1.63	.4	.8	179	.156		
219		240		160	200	40	5	1	2	176	.524		
220		360		320	340	20	17	2.7	5.4	170	.954		
221		430		400	415	15	27.7	15	30	167	1.13		
222	300	318		160	239	79	3.03	.8	1.6	179	.354		
223		350		240	295	55	5.36	1.2	2.4	177	.543		
224		400		320	360	40	9	2	4	175	.719		
225		470		440	455	15	30.3	8	1.6	167	1.17		Belt finally slipped off.
226		450		400	425	25	17	4	8	172	.943	1 m.	
227		450		400	425	25	17	8	16	172	.943	5 m.	
228		450		400	425	25	17	17.3	34.6	172	.943	10 m.	Belt slip'd off.
229		418		360	389	29	13.4	3	6	173	.859	15 m.	Continuing.
230	400	405		160	282.5	122.5	2.30	.8	1.6	179	.267		
232		455		320	387.5	67.5	5.74	1.4	2.8	177	.566		
233		495		400	447.5	47.5	9.42	1.9	3.8	176	.730	1 m.	
234		495	370	400	447.5	47.5	9.42	2.1	4.2	176	.730	5 m.	
235		560		480	520	40	13	2.7	5.4	175	.859	Start.	
236		560		480	520	40	13	4.5	9	175	.859	5 m.	
237		560		480	520	40	13	7.5	15	175	.859	10 m.	
238		550	380	480	465	85	5.47	20	40	178	.547	15 m.	
239	400	560		480	520	40	13	3.4	6.8	175	.859	1 m.	After running 5 m. without load.
240	500	610		480	545	65	8.38	2.1	4.2	177	.688	1 m.	
241		610		480	545	65	8.38	2.5	5	177	.688	5 m.	
242		660		560	610	50	12.2	3.2	6.4	176	.814	1 m.	
243		655		560	607.5	47.5	12.8	8.4	16.8	176	.830	5 m.	Belt slipped off 2 m. later.
244	600	700		560	630	70	9	1.9	3.8	177	.711	1 m.	
245		700		560	630	70	9	2.1	4.2	177	.711	5 m.	
246		690	550	560	625	65	9.69	2.3	4.6	177	.735	10 m.	

TABLE IV.—*Continued.*

No. of Experi'nt.	Sum of Tensions. $T+t$ Initial.	Working.	Final.	$T-t$ Working.	T	t	$\frac{T}{t}$	Percentage of Slip.	Velocity of Slip in ft. per min.	Arc of Contact.	Coefficient of Friction.	Duration of run at time of experiment.	Remarks.
247	600	750		600	675	75	9	2.2	4.4	177°	.711	1 m.	
248		740	585	600	670	70	9.57	2.4	4.8	177	.731	5 m	
249	600	770		640	705	65	10.8	2.5	5	177	.770	1 m.	
250		765		640	702.5	62.5	11.2	3.5	7	177	.782	5 m.	
251		770	600	640	685	85	8.06	4.2	8.4	178	.672	10 m.	
252	600	790		680	735	55	13.4	4.3	8.6	176	.845	1 m.	
253		790		680	735	55	13.4	6.3	12.6	176	.845	5 m.	Belt sl. off 2 m. lat. Pul.warm.
254	100	100		44	72	28	2.57	.6	1.2	176	.307		Belt scraped.
256		160		120	140	20	7	2.1	4.2	172	.648		
257		200		160	180	20	9	4	8	171	.736		
258		230		200	215	15	14.3	6.6	13.2	168	.907	1 m.	
259		230	100	200	215	15	14.3	7.2	14.4	168	.907	5 m.	
261	100	100		44	72	28	2.57	.6	1.2	176	.307		Belt dres'd with preparation recommend'd by maker.
263		160		120	140	20	7	2.8	5.6	172	.648		
264		200		160	180	20	9	5.1	10.2	171	.736		
265		230		200	215	15	14.3	7.3	14.6	168	.907	1 m.	
266		230		200	215	15	14.3	7.9	15.8	168	.907	5 m.	
267		270		240	255	15	17	10.7	21.4	168	.966	1 m.	Belt slipped off 3 m. later.
268	300	350		240	295	55	5.36	1.4	2.8	177	.544		
269		400		320	360	40	9	3	6	175	.719		
270		450		400	425	25	17	6.8	13.6	172	.943	1 m.	Belt slipped off 3 m. later.
271		418		360	389	29	13.4	8.8	17.6	173	.859	1 m.	
272		418		360	389	29	13.4	15.6	31.2	173	.859	5 m.	Belt slipped off 2 m. later.
273	600	700		560	630	70	9	6.3	12.6	177	.711		
274		650		480	565	85	6.65	3.1	6.2	178	.610	1 m.	
275		650		480	565	85	6.65	3.9	7.8	178	.610	5 m.	
276		650		480	565	85	6.65	4.4	8.8	178	.610	10 m.	
277	600	652		400	526	126	4.17	1.4	2.8	178	.460		One day later.
279		715		560	637.5	77.5	8.23	2.4	4.8	177	.682		
280		705		560	632.5	72.5	8.72	2.8	5.6	177	.701		
281		700	560	560	630	70	9	3	6	177	.711		
282	560	750		640	695	55	12.6	4.1	8.2	176	.824	1 m.	
283		735	535	640	682.5	47.5	14.3	22	44	176	.866	5 m.	Belt slip'd off.
284		770		640	705	65	10.7	5.4	10.8	177	.767	1 m.	After 3 min. intermission.
285	300	350		240	295	55	5.36	1.2	2.4	177	.543		Temp. 52°.
286		400		320	360	40	9	1.8	3.6	175	.719		
287		430		360	395	35	11.3	2.7	5.4	174	.798		
289		465		400	432.5	32.5	13.3	5.3	10.6	174	.852		
290		455		400	427.5	27.5	15.5	7.3	14.6	173	.907		
291		460		400	430	30	14.3	11.6	23.2	173	.881		
292	100	100		44	72	28	2.57	.5	1	176	.307		
293		125		80	102.5	22.5	4.55	.8	1.6	173	.502		
294		165		120	142.5	22.5	6.33	1.2	2.4	173	.611		
295		200		160	180	20	9	2.1	4.2	171	.736		
296		230		200	215	15	14.3	3.4	6.8	168	.907		
297		230		200	215	15	14.3	3.9	7.8	168	.907		
298	100	270		240	225	15	17	5.7	11.4	168	.966	1 m.	
299		270		240	255	15	17	7.6	15.2	168	.966	5 m.	[4 m. later.
300		270		240	255	15	17	9.3	18.6	168	.966	10 m.	Belt slipped off
303	100	110		40	75	35	2.14	.1	.4	177	.246		20 in. pulleys.
304		132		80	106	26	4.08	.4	1.6	174	.463		
305		160		120	140	20	7	1	4	172	.648		
306		195		160	177.5	17.5	10.1	1.9	7.6	169	.814		
307		230		200	215	15	14.3	3	12	168	.907	1 m.	
308		230	90	200	215	15	14.3	3.5	14	168	.907	5 m.	
309		270		240	255	15	17	4.5	18	168	.966	1 m.	
310		270		240	255	15	17	5.8	23.2	168	.966	5 m.	
311		270		240	255	15	17	6.2	24.8	168	.966	10 m.	
312		270		240	255	15	17	6.2	24.8	168	.966	15 m.	Temp. 56°.
313		270		240	255	15	17	2	8	168	.966	1 m.	
314		270		240	255	15	17	2.1	8.4	168	.966	5 m.	Temp. 42°.
315		305		280	292.5	12.5	23.4	3.4	13.6	165	1.09	1 m.	
316		305	100	280	292.5	12.5	23.4	3.5	14	165	1.09	5 m.	
317	100	335		320	327.5	7.5	43.7	5.2	20.8	152	1.42	1 m.	
318		335		320	327.5	7.5	43.7	6.5	26	152	1.42	5 m.	
319	300	380		320	350	30	11.7	1.3	5.2	173	.814	1 m.	
320		380		320	350	30	11.7	1.4	5.6	173	.814	5 m.	
321		440		400	420	20	21	2.1	8.4	170	1.03	1 m.	
322		440	260	400	420	20	21	2.4	9.6	170	1.03	5 m.	
323	300	480		440	460	20	23	2.8	11.2	170	1.06	1 m.	Temp. 46°.
324		480	285	440	460	20	23	3	12	170	1.06	5 m.	
325		510		480	495	15	33	3.2	12.8	167	1.20	1 m.	[lat. Pul.warm.
326		510		480	495	15	33	5	20	167	1.20	5 m.	Belt sl. off 5 m.

effect of time upon the percentage of slip. In previous experiments the percentage of slip was measured at once after the load was applied, but it was accidentally discovered that repeated measurements seldom agreed, and investigation showed that these discrepancies were principally due to the duration of the experiment. The continual slipping of the belt was found to cause a deposit of a thick black substance upon the surface of the pulley, which, acting as a lubricant, continued to increase the slip still further.

Upon removing the load on brake-wheel, this deposit would be again absorbed by the belt, and the original adhesion would be restored. The temperature was also found to affect the slipping, and, in general, the colder the weather the slower would this deposit take place.

Experiments 353 to 360 inclusive were made to determine the limit at which the belt would run continuously without increasing its percentage of slip. After the pulleys had become well coated and the slip had reached a high per cent., the load on the brake-wheel was gradually removed until a marked improvement was reached, as shown by experiments 359 and 360. The highest allowable coefficient of friction for this belt is therefore estimated to be somewhere between 1.13 and .995, or we may safely say 1. The highest coefficient obtained was 1.67, but, of course, this was temporary. The diameter of the pulley also appears to affect the coefficient of friction to some extent. This is especially to be noticed at the very slow speed of 18 revolutions per minute on 10 in. and 20 in. pulleys, where the adhesion on the 20 in. pulleys is decidedly greater; but, on the other hand, at 160 revolutions per minute the adhesion on the 10 in. pulleys is often as good, and sometimes better, than appears for the 20 in. at the same velocity of sliding.

It might be possible to determine the effect of pulley diameter upon adhesion for a perfectly dry belt, where the condition of its surface remains uniform, but for belts as ordinarily used it would be very difficult, on account of the ever-changing condition of surface produced by slip and temperature. It is generally admitted that the larger the diameter the greater the adhesion for any given tension, but no definite relation has ever been established, nor, indeed, does it seem possible to do so except by the most elaborate and extensive experiments.

It should be observed, however, that such a variation, if true, implies a corresponding variation in the coefficients of friction for different intensities of pressure upon the same pulleys, and that, consequently, our experiments should show higher coefficients under the lighter loads for the same velocity of sliding. Referring to Table II., where the condition of the belt is dry and uniform for a large range of tensions, we find that this inference is generally sustained, although there are some few exceptions.

Experiment 106 may be compared with 116, and 112 with 133, also 108, 113, and 135, all showing great reductions in the coefficients of friction for increments in tension. The exceptions are all to be found under the smallest velocities of sliding, and appear only in the third decimal place, so that the weight of their record against the probability of such a law is light. By a similar inference it should also follow that a wide belt would drive a little more at a given tension than a narrow one, on account of the reduction in pressure per square inch against the pulley. The mean intensity of pressure of a belt against its pulley may be considered as proportional to the sum of the tensions divided by the product of pulley diameter and width of belt, and an analysis of the experiments referred to will show the relation there existing between intensity of pressure and coefficient of friction.

If we let $I =$ intensity of pressure, and $\varphi =$ coefficient of friction, we shall find that φ is approximately proportional to $I^{-.15}$, or, in other words that doubling the width of belt or diameter of pulley would apparently increase the coefficient of friction about 10 per cent. of its original value. This relation is not proved, of course, and it is given only as a suggestion toward the solution of the question. If the coefficient of friction does vary with the intensity of pressure, the problem of determining the driving power of a belt on strictly mathematical principles will indeed be complicated.

The coefficient of friction in the tables has been calculated by a well-known formula, developed upon the assumption of a uniform coefficient around the arc of contact, but this could no longer be considered as correct if the coefficient is known to vary with the pressure. Referring from Table II. to Table III., we shall find at once the proof and contradiction of the inferences drawn from Table II., and we are left as much in the dark as ever respecting the value of pressure intensity.

Practical millwrights all know, or think they know, that an increase of pulley diameter increases the drive, and it is a matter of common observation that when large and small pulleys are connected by a crossed belt, the smaller pulley will invariably slip first.

On one side a great deal of testimony can be adduced to show that pressure intensity should be an important factor in the theory of belt transmission, and, on the other hand, we have strong evidence to the contrary. I may refer, in this connection, to the experiments of Mr. Holman in *Journal of Franklin Institute* for September, 1885, in which there is no indication that the coefficient of friction varies at all with the pressure. The coefficients obtained by Mr. Holman follow the variations in slip like our own, and it gives us pleasure to observe that our general results and conclusions are so strongly corroborative of each other. There is at the same time a great difference in the methods pursued in arriving at the same results. In his experiments, the velocity of sliding was the fixed condition upon which the coefficient of friction was determined, while, in ours, the conditions were those of actual practice in which the percentage of slip was measured. Our least amount of slip, with a dry belt running at the extremely slow speed of 90 feet per minute, was 1.08 inches, and ten times this would be perfectly proper and allowable. A great many of Mr. Holman's experiments are taken at rates below 1″ per minute, and the coefficients obtained are very much below the average practice, as himself seems to believe.

The velocity of sliding which may be assumed in selecting a proper coefficient is directly proportional to the belt speed, and may safely be estimated at .01 of that speed. For a pair of pulleys we should have .01 on each pulley, and therefore .02 for slip. Few belts run slower than 200 or 300 ft. per minute, and consequently a slip of less than 2 or 3 ft. per minute need seldom be considered. Another point of difference which may possibly affect the coefficients obtained, is that, in Mr. Holman's case the same portion of belt surface was subject to continuous friction, while in ours, the friction was spread over the belt at successive portions as in actual work. This we consider a new and important feature of our experiments. As a matter of practical importance, care was taken to observe, as nearly as possible, the maximum slip which might safely take place before a belt would be thrown from its pulley. A number of observations taken throughout the experiments led to the final conclusion that 20 per cent. of slip was as much as could safely be admitted. This information has been found of value in cases where work is done intermittently by a fly-wheel and the belt has to restore the speed of the wheel, It cannot be said in regard to a maximum value of φ that any was determined or even indicated, although it is certain that the increase at high rates of slip becomes less rapid.

We have now seen that the driving power of a leather belt depends upon such a variety of conditions, that it would be manifestly impracticable if not impossible to correlate them all, and it is thought better to admit the difficulties at once than to involve the subject in a labyrinth of formulæ which life is too short to solve.

The relative value of pulley diameters may vary with different belts, and all that can be expected or desired is some general expression covering roughly the greatest number of cases. Our apparatus did not admit of extensive variations in this respect, and our attention was given principally to the question of slip.

The coefficients given in Table III. are remarkably high, and show a great superiority for the rawhide over tanned leather in point of adhesion. The belt in question was very soft and pliable, but a little twisted from use on a cone pulley where it had rubbed against one side. It is not desirable, on account of its soft and adhesive nature, to use this kind of belt where frequent shifting is required, and when used on cone pulleys it is liable to climb and stretch against the side of the cone; but for a plain straight connection, there seems to be little room for improvement. Table IV. contains the results of similar experiments upon an oak-tanned leather belt made by Chas. A. Shieren & Co. Here the coefficients are much smaller than those given in Table III., and there is quite a marked difference between the coefficients for 10 in. and 20 in pulleys.

As before noticed, the outside temperature has its effect, and it is probable that much lower results would have been obtained had the experiments been made in the heat of midsummer. The high coefficients obtained, together with the rapid increase of tension, show that the pulling power of a long horizontal belt must, in many cases, be limited by its strength rather than by its adhesion.

Table V. gives the results of experiments upon a light planer

TABLE V.

OAK-TANNED LEATHER BELT 2″ WIDE BY $\frac{3}{16}$″ THICK AND 30′ 4″ LONG, WEIGHING 4 LBS., ON 20″ CAST-IRON PULLEYS. DRY AND SMOOTH, TAKEN FROM SERVICE ON PLANER.

No. of Experi'nt.	Sum of Tensions. $T+t$ Initial.	Working.	Final.	$T-t$ Working.	T	t	$\frac{T}{t}$	Percentage of Slip.	Velocity of Slip in ft. per minute.	Arc of Contact.	Coefficient of Friction.	Duration of run at time of experiment.	Remarks.
429	100	110		40	75	35	2.14	1.2	.54	179°	.243		18 r. p. m.
430		115		60	87.5	27.5	3.18	6.1	2.75	178	.372		
431		118		70	94	24	3.92	16.5	7.42	178	.440		
432		105		20	62.5	42.5	1.47	.3	.14	179	.123		
433		112		50	81	31	2.61	3.5	1.57	178	.309		
435	200	204		40	132	82	1.61	.2	.09	180	.152		
436		206		60	133	73	1.82	.7	.32	180	.191		
437		208		80	144	64	2.25	1.8	.81	179	.260		
438		210		100	155	55	2.82	3.7	1.66	179	.332		
439		212		120	166	40	3.61	7.7	3.47	179	.411		
440		215		140	177.5	37.5	4.73	18.4	8.28	179	.497		
442	100	110		60	85	25	3.40	.3	7.12	178	.394		950 r. p. m.
443		120		80	100	20	5	.7	16.62	178	.518		
445		125		90	107.5	17.5	6.14	3	71.25	177	.587	Start.	
446		125		90	107.5	17.5	6.14	25	593.7	177	.587	min.	
448	200	200		80	140	60	2.33	.4	9.5	179	.271		
449		200		100	150	50	3	.5	11.87	179	.352		
450		195	175	120	157.5	37.5	4.20	.8	19.	179	.459		
451	150	175		120	147.5	27.5	5.36	.9	21.38	178	.540		
452	135	160		120	140	20	7	20	475	178	.626		

belt at very slow and very high speeds. As would naturally be expected, much higher coefficients were found at the high speed on account of the greater velocity of sliding.

It may here be mentioned that the sum of the tensions was the horizontal pressure of the belt against the pulleys, and that no allowance was necessary for the effect of the centrifugal force. At the speed here used, the tension indicated in the belt at rest was about 50 lbs. greater than when in motion.

The conclusion to be drawn from this series of experiments is the great importance of high speed in the economy of belt transmission. The friction of belts on pulleys is evidently dependent on the velocity of sliding, and, as a general rule, the greater the velocity the greater the friction. There are but few apparent exceptions to this rule, and investigation of them has led to the inference that in all such cases, the condition of the belt or pulley surface had undergone a change either by heating or by deposit from the belt on the pulley. The percentage of slip is the measure of the power lost in transmission by the belt itself, and the

TABLE VI.

SHOWING THE AVERAGE COEFFICIENT OF FRICTION AND VELOCITY OF SLIP FOR A NUMBER OF EXPERIMENTS IN WHICH THE SLIP APPROXIMATED 2 PER CENT.

No. exper'ts in av'ge.	Percentage of Slip.	Veloc. of Sl. in ft. per m.	Coefficient of Friction.	Belt.	Pulleys.	Remarks.
3	1.4	5.6	.661	5½″ old belt. Table I	20″ diam. pap. cov'd	Belt in nor. w'k'g con.
2	1.7	6.8	.44	5½″ old belt. " I	20″ di. cast-iron sur.	" " "
2	1.55	6.2	.575	5½″ old belt. " I	20″ di. cast-iron sur.	Belt dressed with "Beltilene."
5	1.7	6.8	.452	2¼″ dbl.belt. " II	20″ di. cast-iron sur.	B't dry as us. on plan'r.
2	1.5	6	.818	2¼″ dbl.belt. " II	20″ di. cast-iron sur.	Belt dressed with "Sankey's Life of Leather."
2	1.7	6.8	1.38	4″ r'hide b. " III	20″ di. cast-iron sur.	Belt in nor. w'k'g con.
11	1.8	3.6	.861	4″ r'hide b. " III	10″ diameter.......	" " "
1	2	.45	.432	4″ r'hide b. " III	10″ diameter.......	" " "
1	1.9	.86	.691	4″ r'hide b. " III	20″ diameter.......	" " "
7	1.94	3.88	.617	4″ o.tan'd b. " IV	10″ diameter.......	" " "
4	1.85	7.40	.906	4″ o.tan'd b. " IV	20″ diameter.......	" " "
2	1.5	.67	.251	2″ o.tan'd b. " V	20″ diameter.......	B't dry as us. on plan'r.
2	.8	38	.529	2″ o.tan'd b. " V	20″ diameter.......	" " "

higher the speed the less this becomes. There is a limit, however, to the power which may be transmitted as the speed is increased, and this limit is caused by the reduction in pressure against the pulley arising from the action of centrifugal force.

This point has been clearly demonstrated in a paper read before this Society by Mr. A. F. Nagle on the "Horse Power of Leather belts,"* and the formula there developed is written thus:

$$HP = CVtw\,(S - .012\ V^2) \div 550, \quad . \quad . \quad . \quad (1.)$$

in which C is a constant to be determined from the arc of contact and coefficient of friction as expressed in the equation:

$$C = 1 - 10^{-.00758 fa} \quad . \quad . \quad . \quad . \quad (2.)$$

V = velocity of belt in feet per second.
t = thickness of the belt in inches.
w = width " "
S = working strength of leather in lbs. per square inch.
f = coefficient of friction.
α = arc of contact in degrees.

The velocity at which the maximum amount of power can be transmitted by any given belt is independent of its arc of contact and coefficient of friction, and depends only upon the working strength of the material and its specific gravity.

From equation (1.) we obtain for the maximum power of leather belts the condition:

$$V = \sqrt{28S}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3.)$$

and for any other material whose specific gravity is y, we find

$$V = 5\sqrt{\frac{S}{y}}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4.)$$

The coefficient of friction .40, adopted by Mr. Nagle, appears from these experiments to be on the safe side for all working requirements, except in cases where dry belts are run at slow speeds.

If we assume 2 per cent. as the greatest allowable slip, and select within this limit the coefficient corresponding to the nearest approximations to it, we can form some idea of the coefficients which can be relied upon at different speeds.

Table VI. gives the average results obtained for this maximum allowance of slip, and shows an extreme variation in the coefficient of friction from .251 for a dry oak-tanned belt at the slow speed of 90 feet per minute to 1.38 for a rawhide belt at the moderate speed of 800 feet per minute.

For continuous working, it is probable that the coefficient 1.38 is too high, but still it is certain that a coefficient of 1.00 can be steadily maintained for an indefinite length of time, and we may say that in actual practice the coefficient of friction may vary from .25 to 1.00 under good working conditions. This extreme variation in the coefficient of friction does not give rise, as might at first be supposed, to such a great difference in the transmission of power. It will be seen by reference to formula (1.) that the power transmitted for any given working strength and speed is limited only by the value of C, which depends upon the arc of contact and the coefficient of friction.

For the usual arc of contact, 180°, the power transmitted when $f = .25$ is about 24 per cent. less than when $f = .40$, and when $f = 1.00$, the power transmitted is about 33 per cent. more, from which it appears that in extreme cases the power transmitted may be $\frac{1}{4}$ less or $\frac{1}{3}$ more than will be found from the use of Mr. Nagle's coefficient of .40.

The percentage of slip is the most important factor affecting the efficiency of belt transmission, but in addition to this we have

* Transactions A. S. M. E., Vol. II., page 91. See also Mr. Nagle's Tables I., II., and III., in Appendix VI. to this paper for values of C and *H. P.*

TABLE VII.

SHOWING THE TORSIONAL MOMENT IN LBS. REQUIRED TO OVERCOME JOURNAL FRICTION AND OTHER INTERNAL RESISTANCES, FOR BELTS AT VARIOUS SPEEDS AND TENSIONS ON DIFFERENT ARRANGEMENTS OF PULLEYS.

No. of experim'nt.	Tension. $T + t$	Moment in inch lbs.	Diameter of pulleys.	Revolut's per min.	Width of Belt.	Thickness of belt.	Manner of Driving.	Remarks.
1	100	20	20″	160	6″	$\frac{7}{32}$″	Straight open belt.	
3	300	25						
5	500	30						
7	700	35						
10	1000	45						
45	100	15						
47	300	22.5						
49	500	27.5						
51	700	35						
54	1000	50						
163	100	17.5	20″	160	4″	$\frac{9}{32}$″	Straight open belt.	
165	300	25						
167	500	30						
169	700	35						
194	100	17.5	10″	160	4″	$\frac{5}{16}$″	Straight open belt.	
196	300	27.5						
198	500	40.						
200	700	55.						
202	900	70.						
203	1000	80.						
327	100	20	10″	18	4″	$\frac{5}{16}$″	Straight open belt.	
328	1000	80						
393	100	20						
394	1000	100						
395	600	60						
405	100	20	20″	18	4″	$\frac{9}{32}$″	Straight open belt.	
406	1000	160						
407	600	100						
428	100	20	20″	18	2″	$\frac{9}{32}$″	Straight open belt.	
434	200	25						
441	100	25	20″	950	2″	$\frac{3}{16}$″	Straight open belt.	
447	200	30						
453	100	25	20″	160	6″	$\frac{7}{32}$″	Crossed belt.	14′ 6″ between pulleys.
454	500	60						
455	1000	110						14′ 6″ bet. pul'ys.
459	100	15	20″	160	6″	$\frac{7}{32}$″	Straight open belt.	14′ 6″ between pulleys.
460	500	25						
461	1000	65						
462	100	25	20″	160	6″	$\frac{7}{32}$″	Straight open belt.	With 8″ tightener.
463	500	60						
464	1000	110						
465	100	45	20″	160	6″	$\frac{7}{32}$″	Crossed belt.	8 feet between pulleys.
466	500	105						
467	1000	180						
470	100	25	20″	160	6″	$\frac{7}{32}$″	Quarter turn belt on 16″ diameter mule pulleys.	
471	500	80						
472	750	145						
473	1000	250						
474	750	170						
475	500	110						
476	1000	220						
477	1000	140	20″	160	6″	$\frac{7}{32}$″	Quarter turn belt on 16″ diameter mule pulleys.	Freshly oiled.
478	750	100						
479	500	70						
480	100	20						
481	50	60	20″	160	6″	$\frac{7}{32}$″	Quarter turn on 16″ mule pulleys.	Belt rub. against low.guide m.pul.
482	25	120						
483	100	20	20″	160	6″	$\frac{7}{32}$″	Quarter turn on 16″ mule pulleys.	Well oiled, after a run of 2 hrs. at $T + t = 100$.
484	500	50						
485	750	70						
486	1000	105						
495	250	30	20″	160	6″	$\frac{7}{32}$″	Half turn belt on 16″ mule pulleys.	
496	500	50						
497	750	90						
498	1000	170						
503	1000	260	20″	160	6″	$\frac{7}{32}$″	Quarter twist.	10 feet between pulleys.
504	750	190						
505	500	130						
506	250	80						
507	100	30						
513	100	50	20″	160	6″	$\frac{7}{32}$″	Quarter twist.	7′ 6″ between pulleys.
514	250	105						
515	500	200						
516	750	290						
517	1000	380						
523	100	25	20″	160	4″	$\frac{1}{4}$″	Quarter twist.	10 feet between pulleys.
524	250	50						
525	500	95						
526	750	145						
527	1000	210						
528	100	65	20″	160	4″	$\frac{1}{4}$″	Quarter twist.	6 feet between pulleys.
529	250	135						
530	500	245						
531	750	380						
533	100	25	20″	160	6″	$\frac{7}{32}$″	Quarter twist.	16′ 6″ between pulleys.
534	250	40						
535	500	75						
536	750	105						
537	1000	165						

TABLE VII.—*Continued.*

No. of experim'nt.	Tension. $T+t$	Moment in inch lbs.	Diameter of pulleys.	Revolut's per min.	Width of Belt.	Thickness of belt.	Manner of Driving.	Remarks.
539	1000	130	20″	160	6″	$\frac{7}{32}$″	Quarter twist with 16″ diameter carrying pulley.	7′ 6″ between pulleys.
540	750	110						
541	500	90						
542	250	60						
543	100	40						
544	100	30						
545	250	55						
546	500	90						
547	750	120						
548	1000	170						
569	100	25	20″	160	6″	$\frac{7}{32}$	Straight open belt.	
571	500	55						
572	750	70						
573	1000	90						

journal friction, the resistance of the air, and with crossed belts the friction of the belt upon itself. These have been termed internal resistances, and their values for some of the most common arrangements of pulleys are given in Table VII. From this table it appears that the moment required to run a straight belt varies from 15 to 25 inch lbs. at 100 lbs. tension for all speeds. At 160 revolutions per minute and 1,000 lbs. tension, the required moment varied from 45 to 90 inch lbs., and at 18 revolutions per minute and at the same tension it varied from 80 to 150 inch lbs.

From the average of these quantities we find the moment of resistance to be expressed by the following formulæ for straight open belts between 2″ journals:

At 160 r. p. m.:

$$M = .053\ S + 14.7, \qquad (5.)$$

At 18 r. p. m.:

$$M = 11.\ S + 9, \qquad (6.)$$

in which

$M =$ moment of resistance in inch lbs.
$S =$ sum of tensions.

When a crossed belt does not rub upon itself, the resistance is the same as for an open belt.

The resistance offered by the introduction of carrying pulleys and tighteners is appreciable, and depends upon the pressure brought to bear against their journals. If the belt rubs against the flanges of the carrying pulleys, the resistance is very much increased, and this is often liable to occur in horizontal belts from a change of load. The friction on journals of carrying pulleys may be estimated by the formulæ already given if we substitute for S the pressure against their journals. In the experiments which were made upon internal resistances, the greatest resistance was offered by a quarter-twist belt 6 feet between journals on 20-inch pulleys.

The equation for this belt may be written:

$$M = .35\ S + 58, \qquad (7.)$$

but the introduction of a carrying pulley reduced the resistance to no more than what might be expected from the same number of journals with a straight belt.

With quarter-twist belts the resistance lies chiefly in slip, which occurs as the belt leaves the pulleys, and this naturally depends upon the distance between journals in terms of the diameters of the pulleys.

The effect of time upon the tension of the belt used in Table VIII. is plainly shown by experiments 588 to 613 inclusive, between which the pulleys remained at a fixed distance apart, and the belt slowly stretched from a tension of 380 to 280 lbs.

To estimate the efficiency of belt transmission for an average case, we may assume 40 in. lbs. as the moment of internal resistance for a belt whose tension is 500 lbs. and 40 in. lbs. statical moment = about 20 ft. lbs. per revolution. If the belt is transmitting 400 lbs. with two per cent. of slip on 20 in. pulleys, then $.02 \times 400 \times 5 = 40$ ft lbs. are lost per revolution in slip, making a total loss of 60 ft. lbs. per revolution.

TABLE VIII.

SHOWING THE INCREASE IN THE SUM OF THE TENSIONS ON A VERTICAL BELT 4″ WIDE BY $\frac{1}{4}$″ THICK, AND 24 FT. LONG, ON 20″ CAST-IRON PULLEYS, AT 120 R. P. M.

No. of experim'nt.	Scales A.*	Scales B.*	Tension $T+t$	Tension $T-t$	T	t	Increm'nt of $T+t$	Percent'e of Increment.	Date.
578	93	101	194	16	105	89	0		5—15—1885.
579	70	142	212	144	178	34	18		
580	67	170	237	206	221.5	15.5	43		
581	66	180	246	228	237	9	52		
582	66	188	254	244	249	5	60	.323	
583	91	101	192	20	106	86	— 2		
584	202	210	412	16	214	214	0		5—15—1885.
585	167	250	417	166	292.5	292.5	5		
586	145	300	445	310	376.5	376.5	33	.171	
587	185	195	380	20	200	200	—32		
588	190	199	380	0	190	190	0		5—18—1885.
589	133	250	393	214	303.5	89.5	13	.033	
590	177	177	354	0	177	177	0		5—19—1885.
591	156	203	359	94	226.5	132.5	5		
592	138	235	373	194	283.5	89.5	19		
593	135	250	385	230	307.5	77.5	31		
594	128	275	403	294	348.5	54.5	49		
595	125	300	425	350	387.5	37.5	71		
596	123	325	448	404	426	22	94	.333	
597	168	168	336	0	168	168	—18		
598	143	143	286	0	143	143	0		5—25—1885.
599	140	148	288	16	152	136	2		
600	130	160	290	60	175	115	4		
601	122	170	292	196	194	98	6		
602	116	180	296	28	212	84	10		
603	112	190	302	156	229	73	16		
604	108	200	308	184	246	62	22		
605	105	210	315	210	262.5	52.5	29		
606	102	220	322	236	279	43	36		
607	100	230	330	260	295	35	44		
608	99	240	339	282	310.5	28.5	53		
609	98	250	348	304	326	22	62		
610	98	260	358	316	337	21	72		
611	99	270	369	342	355.5	13.5	83		
612	100	280	380	360	370	10	94	.357	
613	140	140	280	0	140	140	— 6		

* Scales A recorded the reduction of the load on the testing device for *vertical* belts by the tension of the loose part of the belt (t.) Scales B, by that of the tight side of the belt (T).

The total power expended per revolution is about 2,000 ft. lbs., therefore .03 is lost.

Under light loads, the internal resistance, which is nearly constant in amount, may be a large percentage of the power transmitted, while under heavy loads the percentage of slip may become the principal loss.

It would be difficult to work out, or even to use, a general expression for the efficiency of belt transmission, but, from the foregoing, it would seem safe to assume that 97 per cent. can be obtained under good working conditions.

When a belt is too tight, there is a constant waste in journal friction, and when too loose, there may be a much greater loss in efficiency from slip. The allowance recommended of 2 per cent. for slip is rather more than experiment would indicate for any possible crawl or creep due to the elasticity of the belt, but in connection with this, there is probably always more or less actual slip, and we are inclined to think that in most cases this allowance may be divided into equal parts representing creep and slip proper. Under good working conditions, a belt is probably stretched about 1 per cent. on the tight side, which naturally gives 1 per cent. of creep, and to this we have added another per cent. for actual slip in fixing the limit proposed.

The indications and conclusions to be drawn from these experiments are:

1. That the coefficient of friction may vary under practical working conditions from 25 per cent. to 100 per cent.

2. That its value depends upon the nature and condition of the leather, the velocity of sliding, temperature, and pressure.

3. That an excessive amount of slip has a tendency to become greater and greater, until the belt finally leaves the pulley.

4. That a belt will seldom remain upon a pulley when the slip exceeds 20 per cent.

5. That excessive slipping dries out the leather and leads toward the condition of minimum adhesion.

6. That rawhide has much greater adhesion than tanned leather, giving a coefficient of 100 per cent. at the moderate slip of 5 ft. per minute.

7. That a velocity of sliding equal to .01 of the belt speed is not excessive.

8. That the coefficients in general use are rather below the average results obtained.

9. That when suddenly forced to slip, the coefficient of friction becomes momentarily very high, but that it gradually decreases as the slip continues.

10. That the sum of the tensions is not constant, but increases with the load to the maximum extent of about 33 per cent. with vertical belts.

11. That, with horizontal belts, the sum of the tensions may increase indefinitely as far as the breaking strength of the belt.

12. That the economy of belt transmission depends principally upon journal friction and slip.

13. That it is important on this account to make the belt speed as high as possible within the limits of 5,000 or 6,000 ft. per minute.

14. That quarter-twist belts should be avoided.

15. That it is preferable in all cases, from considerations of economy in wear on belt and power consumed, to use an intermediate guide pulley, so placed that the belt may be run in either direction.

16. That the introduetion of guide and carrying pulleys adds to the internal resistances an amount proportional to the friction of their journals.

17. That there is still need of more light on the subject.