ALIGNMENT CONSIDERATIONS
AND SAFETY ISSUES
IN THE USE OF TURNING ROLLS

Unless a vessel has been turned between centers in a lathe by a skilled machinist, the vessel will never be a true cylinder; exactly round, both ends the same diameter, no taper, and the centerline exactly straight.

Vessels are commonly made from rolled plate; heavier vessels made from plate so thick that it must be formed in tremendous rolls and presses. It is unrealistic to expect each section of a vessel to be exactly like other sections, or that sections can be joined to make exactly true courses.

For practical reasons, it is impossible to form plate in a roll or press so that its curvature is continuous to the very end. In addition, when prepared-edge buttweld joining is used, the shrink and pull of the weld tends to flatten the plate near the weld seam. Even if the weld bead is ground flush and smooth, there is always a flat or other deviation from true curve at the seam.

In discussing alignment of turning rolls, we will consider the vessel is a true cylinder and then attempt to provide turning rolls which have the necessary precision to ensure adequate alignment. Then, if the vessel creeps endwise or some other alignment trouble arises, it will not be the fault of the rolls. It is most difficult to solve a problem with a problem-producing solution.

Figure 1 shows Driver and Idler turning rolls in perfect alignment within themselves and with the true-cylinder vessel.

The top view shows that all four wheels are parallel, wheel centers are equidistant from the vessel centerline, wheel axes are perpendicular to the vessel axis, and that the centerline of the plane of the two wheels in each turning roll frame is perpendicular to the centerline of the cylindrical vessel.

End view shows that x, y and z are equal, so the axes of all the wheels are all the same distance above the flat and level floor. Side view shows that the plane of the wheels is vertical and that the wheels do not toe-in or toe-out.

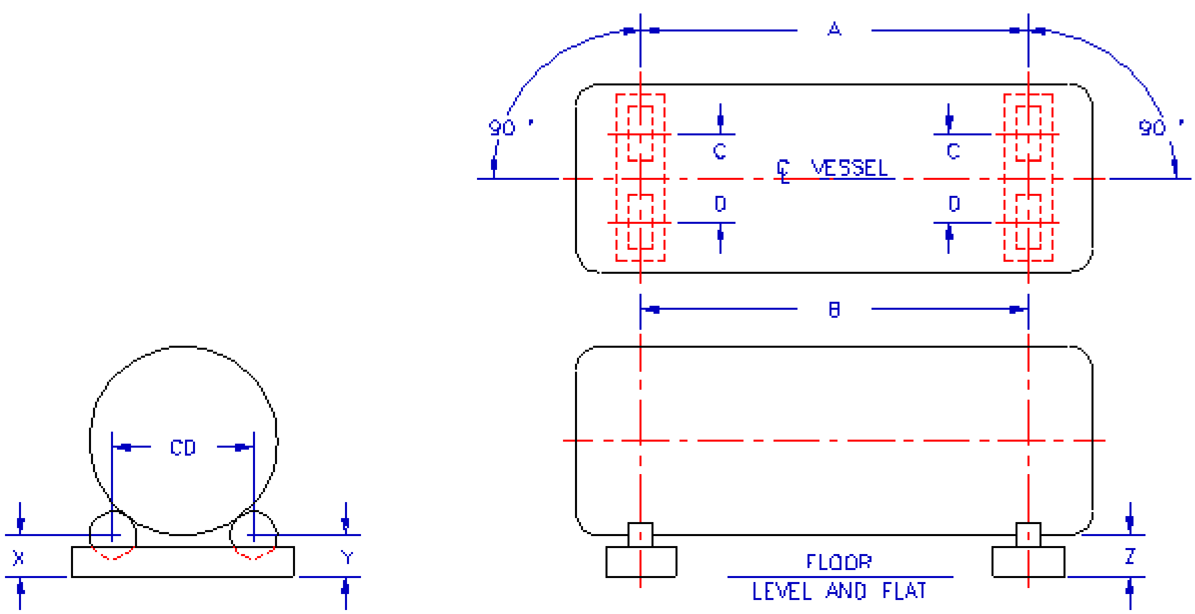


FIGURE 1 - PERFECT TURNING ROLL AND VESSEL ALIGNMENT

ENDCREEP of vessels rotated in turning rolls is practically impossible to completely eliminate because endcreep occurs in many ways. However, endcreep will not be prohibitive of the most precise automatic welding of fairly true cylindrical vessels if top quality turning rolls are used and are properly aligned. Top quality turning rolls can always be "tuned" in alignment under almost any approximately uniform cylindrical vessel so that even a 12-foot diameter vessel will endcreep no more than 1/16 inch per revolution.

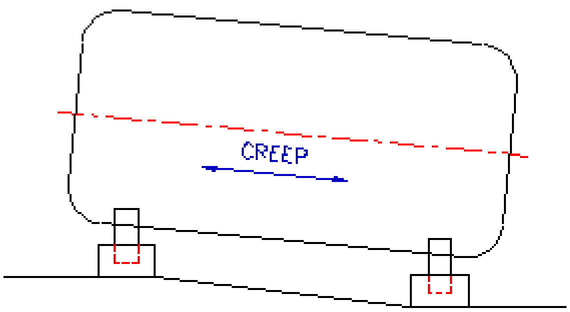


FIG. 2A - UNEVEN FLOOR = ENDCREEP

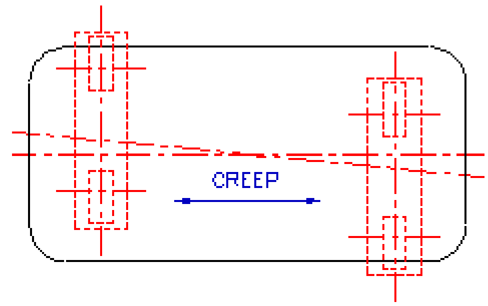


FIG. 2B - STAGGERED CHASSIS = ENDCREEP

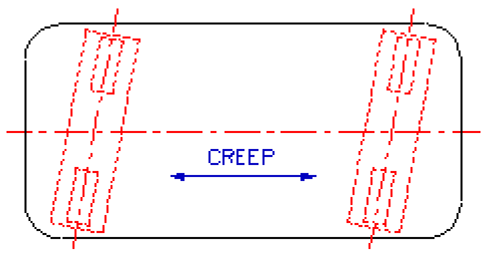


FIG. 2C - COCKED CHASSIS = ENDCREEP

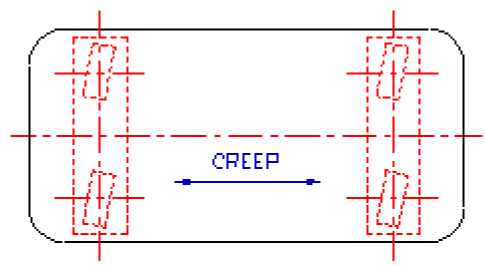


FIG. 2D - COCKED WHEELS IN CHASSIS = ENDCREEP

The user caused the endcreep by his misalignment in Figures 2A, 2B, and 2C. The manufacturer's poor design and workmanship caused the endcreep in 2D. Whatever the cause of the endcreep, IT CAN NOT BE CONTAINED BY END STOPS. An endcreeping vessel exerts many times its weight against an end stop exactly the same as a nut turning on a screw exerts many times more thrust than the pounds load on the handle of the wrench. The only solution possible is well-designed turning rolls properly aligned under the vessel. It is not only possible; it is being done thousands of times every year.

EXCESSIVE ROTATIONAL DRAG is the result of misalignment causing the wheels to fight each other, whether due to the user's pigeon-toed installation or the manufacturer's unparalleled wheels. At least half of a Drivers "Tractive Pull" is expended in overcoming the rotational drag in Figures 3A and 3B.

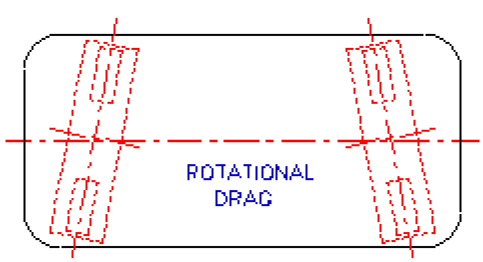


FIG. 3A - PIGEON-TOED CHASSIS DRAG

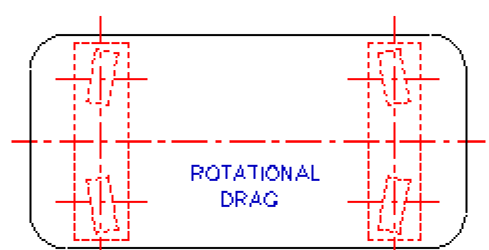


FIG. 3B - UNPARALLELED WHEELS DRAG

A solution to some misalignment problems may be obtained by placing a smooth, flat steel plate on a leveled section of shop floor and letting the rolls rest on the plate without them being lagged down. This allows the turning rolls to seek their own best alignment, or, at the least, makes it easier to jog a turning roll end one way or the other in "tuning" for best alignment.

INHERENT OVERLOAD PROBLEMS OF TURNING ROLLS.

Figure 4 is an exaggeration of the bent axis any vessel will have to some degree. The 90,000-Lb., rather long vessel is supposedly supported on three 30,000-pound turning roll units: one Driver and two Idlers. With the vessel belly-up, the Driver on the left end and the Idler on the right end have to each take half the load, 45,000 pounds, a 50% overload. Then, 180 degrees later, the vessel is belly-down and the whole 90,000 pounds is carried on the middle Idler, 300% of rated load capacity. Of course, the vessel will not revolve the 180 degrees because there will not be any traction on the Driver. You can not put the Driver in the middle because it will not get any weight from which to derive traction when the vessel is belly-up. To make Figure 4 work at all, the middle Idler has to be placed enough off-center and away from the Driver so the Driver always has at least some weight from which to derive the needed Tractive Pull.

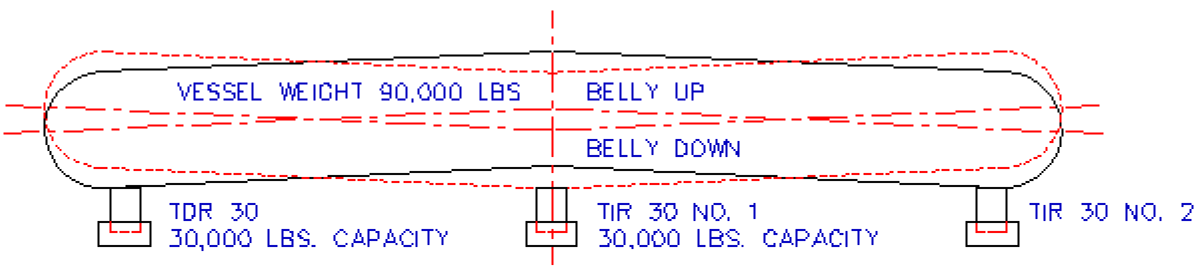


FIGURE 4 - INHERENT OVERLOAD: LONG VESSEL, BENT CENTERLINE, THREE ROLL UNITS

By exaggerating the bent axis of the 90,000-Lb. vessel, we are able to show you the daylight at the inboard side of the wheels. You can visualize that if there were only two roll units, the weight of the vessel would move from the outboard to the inboard edges of the wheels as the vessel was rotated. This is an overload in itself because less than the full face of the wheel ever has a chance to shoulder the load. This is why a person never plans an overload and always uses turning rolls made by a manufacturer who is aware of the inescapable inherent overload aspects.

Whenever possible, a vessel should be supported in a "cradle" of only four wheels; as when a 2-wheeled Driver is used with one 2-wheeled Idler. Figure 4's 90,000-Lb. vessel should be cradled in one 60,000 pound TDR 60 Driver and one 60,000 pound TIR 60 Idler, affording 120,000 pounds load capacity. Then, whether belly-up or belly-down, the two units share the load equally, and the Driver would always have half the weight from which to derive traction.

When the vessel is quite long and/or the joining of courses requires more than one Idler for support and alignment, always specify turning roll units with more rated capacity than would be specified for a 4-wheel-cradled application. For a while, we will continue to discuss only the weight of the load, and later when we discuss turning capacity it will become still more apparent why multiple Idlers demand extra capacity in the Driver. Top quality turning rolls have built-in overload protection and extra safety factors, but these are generally totally needed to combat the inescapable inherent overloads a person can not plan out of the application.

Three elements are immediately and critically effected by the inescapable inherently overloading nature of vessels being supported in turning rolls whether the simple 4-wheel cradle or the multiple-idler set-up: (1) Axle Bearings, (2) Tires, (3) Axles.

AXLE BEARINGS (As Affected by Overloads)

Axle Bearings of turning rolls carry very high loads at very slow speed and are subject to severe shock loading when the vessel is roughly lowered by the crane into the turning roll. Plain bearings (bushings) lack the necessary characteristics: anti-friction nature, ability to bold alignment, and simplicity of lubrication, to name a few. A taper roller bearing's forces of adjustment assure good contact between the rollers and the races and afford maximum thrust support. Timken Tapered Roller Bearings serve turning rolls admirably.

Radial and thrust ratings of Timkens are shown in the engineering manual for 500 rpm and 3,000 hours of life expectancy. To obtain static and 1 rpm ratings, simply multiply by 4. Many tests have determined the shock capacity to be FOURTEEN TIMES the 500 rpm rating. Selecting axle Timkens on the basis of normal static rating and then allowing 2-to-1 for the inherent overload, the axle Timkens have a safety factor of 7-to-1 in relation to the turning roll's catalog rating.

Figure 5 has a 120,000 Lb. vessel "cradled" in a set of one TDR 60 Driver and one TIR 60 Idler, each rated 60,000 Lbs., the set rated at 120,000 Lbs.; 1-to-1 with the vessel load. Theoretically, half of the 120,000 Lbs. (60,000) is on each unit, and half of that, (30,000) is on each wheel.

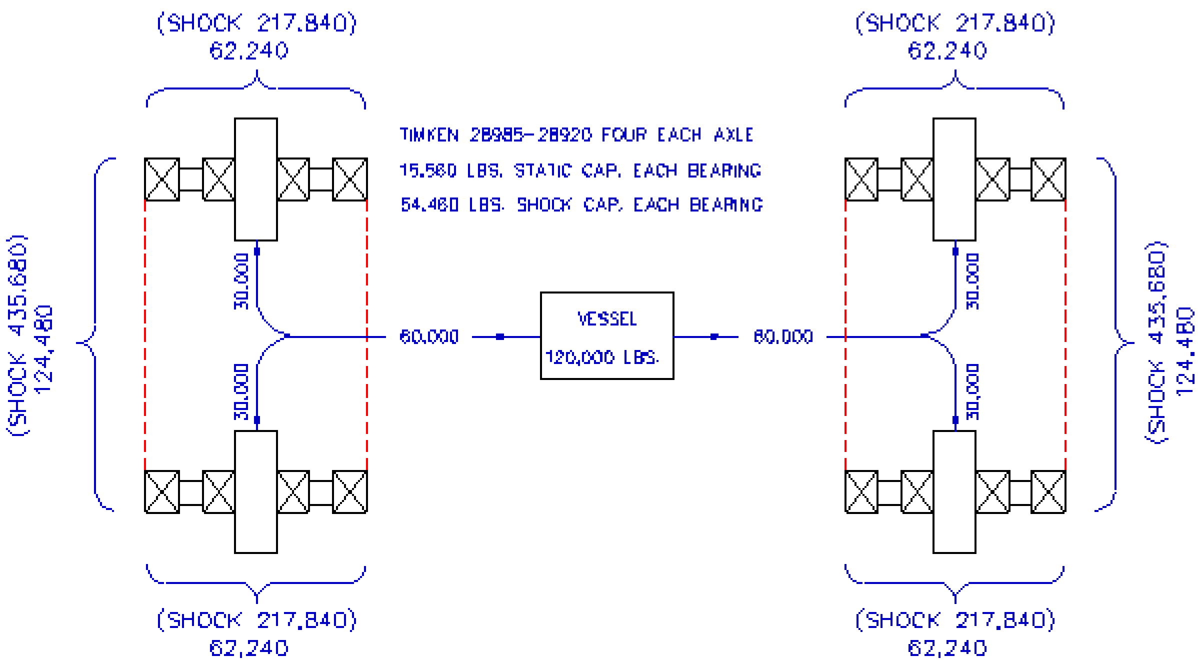


FIGURE 5 - LOAD DISTRIBUTION AND AXLE BEARING CAPACITY

Size -60 axle journals are 2-3/8 inch and the bearings are Timken 28985-28920 cone and cup, rated 3890 radial capacity at 500 rpm, 15,560 at static, 1 rpm, and have 54,460 Lbs. of shock capacity. Each axle has four of these Timkens, opposed in pairs for rigid alignment, so each wheel has a load capacity of 62,240 Lbs. to cover the rating of 30,000 Lbs. and each wheel is capable of withstanding a shock of 217,840 pounds...Almost twice the total weight of the vessel! If all of the vessel's weight rested on one of the units, Driver or Idler, the bearings have a normal rating of 124,480 Lbs. to cover the vessel's 120,000 Lbs.

TIRES

Figure 6A is a cross-section of an industrial solid rubber tire bonded to its steel rim, and the rim and tire pressed onto an ordinary turning roll wheel. The O.D. edges of the rubber tire have a radius and the sidewalls have a prominent slope which is intended to permit the free deformation which occurs when the tire is subjected to a load. Extra width tires usually have a tread design, not for better traction, but to afford some space for the extra deformation. Rubber does NOT compress--it deforms and changes shape.

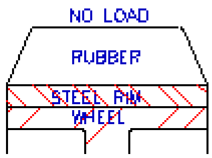


FIGURE 6A

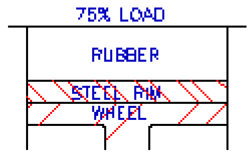


FIGURE 6B

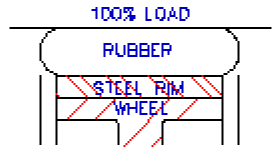


FIGURE 6C

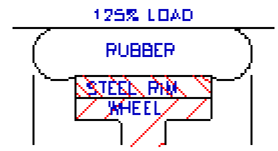
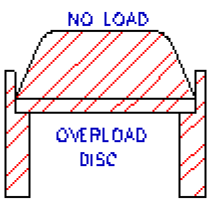
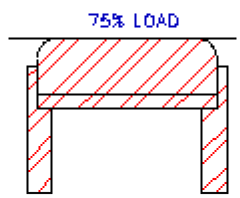
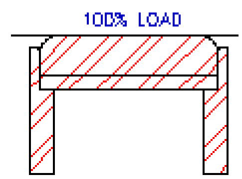


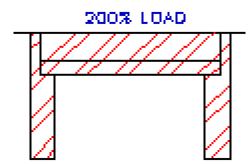
FIGURE 6D

Figure 6B shows that a 75% load deforms the sidewalls to about flush with the plane of the rims. At 100% load, Figure 6C, there is some bulging-out at the sides which tends to loosen the bond at the edges of the rims. In a condition such as shown in Fig. 6I, where the load concentrates first on one side and then the other, the bond is further broken until the tire is completely unbonded. When the load reaches 125% of rating, Figure 6D, even if the load is full-face, the rubber spills over the sides and breaks the bond between the rubber and steel rim, and the ruptured tire soon works itself off the steel rim entirely.









OVERLOAD DISCS ARE THE WHEELS

FIGURE 6E FIGURE 6F FIGURE 6G FIGURE 6H

Figure 6E is the better approach to the problem of supporting vessels on rubber-tired turning rolls. OVERLOAD DISCS of steel serve the two purposes of preventing tire rupture under normal conditions and forming the wheels which mount the tires. The Overload Discs are the wheels, and therefore do not add directly to increased cost of manufacture. Considerable skill in design and manufacture is required to afford exactly the necessary triangular space between tire sidewall and overload disc so that the tire can deform into the space as shown in Figure 6F at 75% of rated load and not abrade or scar the tire sidewall.

Figure 6G shows that when 100% load is applied the vessel still does not rest on the overload discs. This is because the rubber is firmed-up as it deforms more and more into the restricted spaces afforded by the overload discs. At approximately 200% of rated load, the vessel surface comes into contact with the O.D. of the overload discs. In no case can the tire spill over the edge or loosen itself from the bond it should have with the steel rim.

In Figure 6I however, if the vessel contacts the wheel as shown, even a 75% load can bear brutally on the overload disc, first one side and then the other as it rotates, and can deform the edges of the steel disc. Still, the tire is protected and overload discs prolong the life of the brutalized wheels.

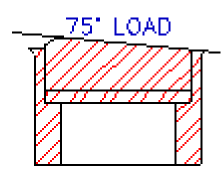


FIGURE 6I - CANTED WHEEL CONDITION

DYNAMIC FORCES - LOADING THE VESSEL

As shown in Figure 7, the act of loading the vessel is the most damaging moment in a turning roll's life. The entire impact force of rough crane operation is absorbed in one final drive gear's teeth.

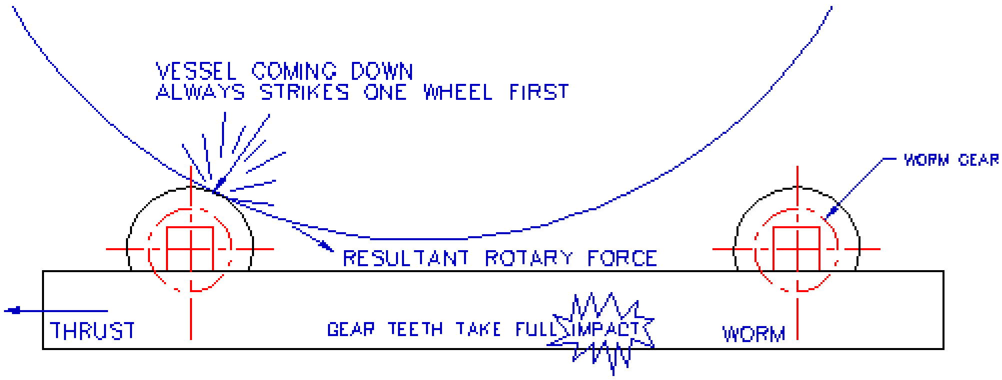


FIGURE 7 - WHEN LOADING THE VESSEL, IT ALWAYS STRIKES ONE WHEEL FIRST

One and one only final drive gear is bound to absorb the entire shock of loading because it is impossible for any vessel to be so accurately lowered as to touch down on all four wheels simultaneously. We already know that a vessel is never a perfect cylinder, nor are the rolls ever absolutely aligned, so even the very best craneman can not lower a vessel down evenly and equally on all the turning roll wheels assigned to support the total weight of the vessel.

We have shown that the bearings, axles and tires must be prepared to take shock loads several times their rated loads. Now we must provide a final drive system that will allow each final drive the necessary strength to absorb the full and total impact of the entire vessel. Even if all four wheels in a set-up of one Driver and one Idler were to be "improved upon" so that all four wheels were driven--thus making both units Drivers--still, during the moment of touch-down while loading the vessel, any one of the four geared wheels has to be equal to absorbing all the impact force because the vessel will always strike one and only one of the four wheels first.

When lowering the vessel into the "cradle" of the Driver's two wheels the vessel moves straight down and is not centered between the two wheels. If the vessel's diameter is so great that its point of impact is straight up from the center of the axle there would be no tangential force. However, the vessel can not be so large in diameter that it will strike one wheel at an angle inboard froin vertical, producing a great shocking tangential force.

The greater the distance between wheels, the more the vessel "cradles" into the wheels, and the greater the tangential force. The wheel is held by its axle and bearings and can not move perpendicular to the line of tangent force. The result is a rotary force that tries to revolve the wheel. For safety, the final drive is selflocking against any, except intentional, powered rotation, so the full impact of the resultant rotary force is taken in the teeth of the final drive gear.

ROTATING THE VESSEL

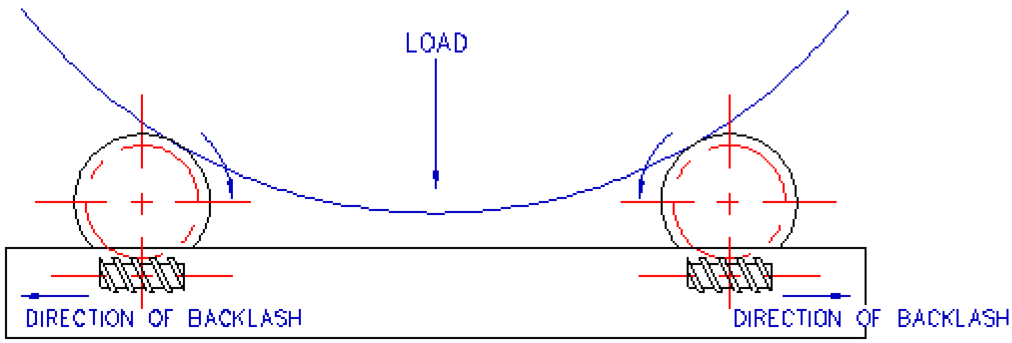


FIGURE 8 - BACKLASH ALWAYS LOADS OPPOSITELY AS THE VESSEL CRADLES INTO WHEELS

The resultant rotary force shown in Figure 8 acts inwardly on the second wheel touched-down, just the same as it did on the first wheel. All the backlash between the teeth of the wormgear and the threads of the worm is taken out in opposite directions. Regardless of how finely engineered a design is, and how skillfully it is built and aligned, mating gears always have some working clearance at the teeth for lubrication and to avoid galling. Even if a pair of gears were put together without backlash, in a short time they would generate backlash through wear. Without engineered backlash, wear is greatly accelerated.

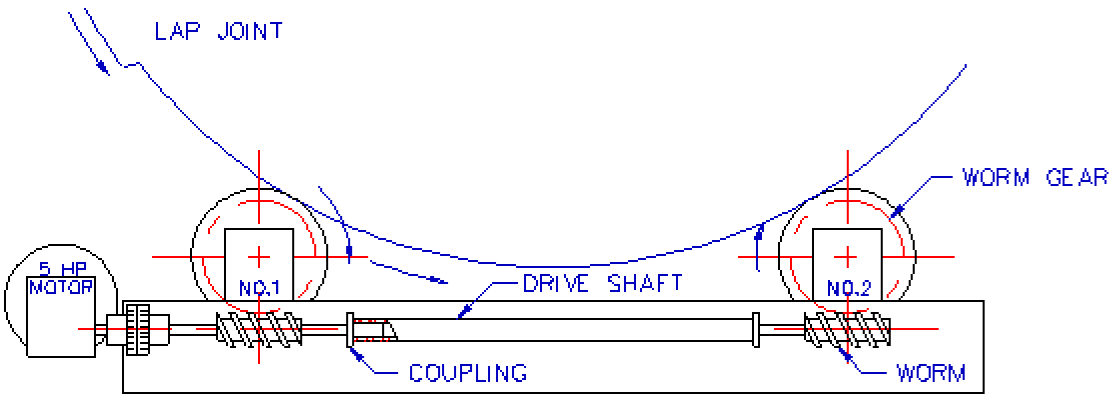


FIGURE 9 - NORMALLY, ONLY ONE WHEEL DRIVES WHEN ROTATING THE VESSEL

Figure 9 shows that once the heavy vessel is resting firmly on the two wheels of the Driver turning roll, those two wheels are bound to revolve with the vessel, unless one or both wheels slip. The two worms are positively joined by the driveshaft and couplings and must revolve in unison. With the teeth of the two self-locking wormgears loaded against the threads of their worms in opposite directions, one set of worm and wormgear is ready to perform the work of rotation in one direction and the other set is ready to perform work in the opposite direction.

When the motor starts, the vessel is rotated by the effort of only that one final drive whose backlash has been loaded against that direction of rotation, which relieves No.1 and puts No. 2 to work because No. 2 has had its backlash loaded against rotation in this other direction. Only if one wheel slips can the two drives ever share the work. Driving force is not increased because there are two final drives, but total life is doubled.

Figure 7 graphically illustrates that the most damaging moment in a Driver turning roll's life is when the vessel is being loaded into the rolls and strikes one of the self-locked wheels first. The second most damaging moment is when a lapjoint or similar obstruction strikes one wheel as it is about to do to No. 1 in Figure 9. Even if one wheel has slipped and both wheels actually are sharing the rotational drive load, the moment the lapjoint strikes No. 1 wheel the full effort of rotation is concentrated in No. 1 wheel and final drive. The radius of the vessel is increased by the thickness of the overlap, and in order for the vessel to pass over the wheel, the vessel has to be lifted by the wheel and its drive gearing. The opposite wheel can not help do this lifting; its turn will come when the lapjoint reaches it.

If the vessel could be so big that it could contact the wheels straight up from their centers, the reaction of lifting force would be straight down on the axle and its bearings. However, the vessel cradles between the wheels and makes contact at an angle from vertical, so the lifting is done by the shock increase in tangential force the moment the lapjoint strikes the wheel. Tangential force always results in a rotary force when the members are restricted by axles and bearings.

The shift of rotation task from wheel to wheel as the lapjoint hits first one wheel and then the other demands that the full power of the motor be likewise shifted from one final drive to the other. A certain amount of power is required to rotate a vessel and all of that power must be transferrable from one wheel to the other as demanded by the passing of the lapjoint.

Figure 9 shows the motor's total horsepower is applied to the wormshaft of No. 1 final drive. When the lapjoint task momentarily concentrates at No. 1 wheel, all the motor's power is momentarily available to No. 1. When the lapjoint progresses on to No. 2, the task on No. 1 is momentarily relieved and all of the motor's power is transmitted straight through the driveshaft to No. 2's wormshaft. If the power required to rotate the vessel is found to be 5 horsepower, all 5 horsepower is first concentrated in No. 1 when the lapjoint hits No. 1 and then all 5 horsepower is concentrated in No. 2 when the lapjoint hits No. 2.

UNBALANCED-LOAD DYNAMICS

Figure 10 shows a vessel which needs no lapjoint to effect a shifting of load and rotation task from one wheel to the other. The task-shift resulting from a vessel having an unbalanced Center of Gravity is not momentary but is of considerable duration. The requirement in Figure 10 is for a prolonged transfer of driving effort from one wheel to the other as the unbalance shifts steadily from one side to the other.

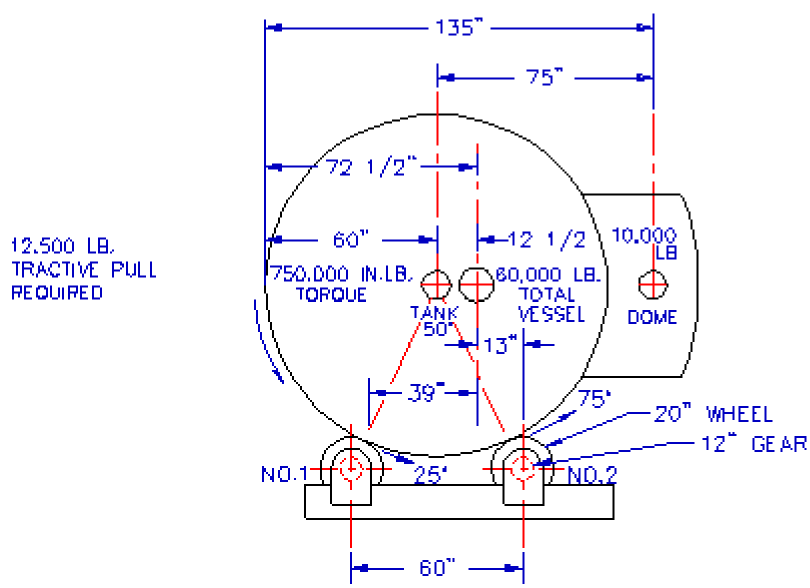


FIGURE 10 - VESSEL WITH ECCENTRIC CENTER-OF-GRAVITY

A smooth cylindrical tank weighing 50,000 Lbs. has a dome weighing 10,000 Lbs. welded to one side, making a complete weldment weighing 60,000 Lbs. The CG of the 120 inch diameter, 50,000 Lb. tank is on the centerline axis. The CG of the dome is 75 inches off-center, bringing the CG of the whole 60,000 Lb. vessel 12.5 inches off the axis of rotation, toward the dome.

When the dome is straight up or down, the 60,000 Lb. CG is centered between the two wheels and the weight will be equal on both wheels. Rotating the vessel a quarter-turn shifts the concentration of weight 90° and puts the CG nearer the wheel on the side of the dome so the "near" wheel now has 75% of the weight while the "far" wheel has only 25%. If the vessel's CG were 13 inches farther off-center, the vessel would teeter on wheel No. 2 and there would not be any weight at all on wheel No. 1.

When there is only 25% of the weight bearing down on wheel No. 1, it is totally unrealistic and impossible for drive No. 1 to do more than 25% of the work of rotating the vessel. Conversely, the No. 2 wheel has to accomplish the other 75% of the task. In other words, a two-motor drive will be short of power in spite of the total amount of horsepower "available"; and if the dome weighed 20,000-Lbs,, the CG would be over the No. 2 wlieel enough so the No. 1 wheel would not have any weight to speak of and very little weight fron which to derive traction.

If the desired rate of rotation is 5 minutes per revolution, the rotation speed is .2 RPM and the surface speed is 75.4 Inches Per Minute. The 60,000 Pounds is 12.5 inches off-center and amounts to 750,000 Lb.In. torque about the axis of the tank. One horsepower equals 63,025-Lb.-In.@ 1 RPM. To find the horsepower required to pull the vessel up to and over the 90° position, multiply 750,000 Lb.In. by .2 RPM and divide the answer by 63,025 and you get 2.38 HP <u>required at the tire O.D.</u>

Turning rolls are approximately 50% efficient. The best drive layout uses a self-locking worm drive as the final drive, but wherever the self-locking worm drive may be, it is still a worm drive. Something has to reduce the 1,800 RPM of the motor down to the approximately 1 RPM of the wheels. A 20-inch wheel has a 62.83-inch circumference and 1 RPM is about 63 IPM surface speed on the vessel. In Driver turning rolls, there are usually two worm drives, as in Figure 10. So, 50% efficiency is commonly to be expected, and at this efficiency there will be only about half of the motor's horsepower left by the time it gets to the wheels.

Experience has proven that it is not unusual for half of the power <u>at the wheel O.D.</u> to be drowned in frictional resistance to rotation of the vessel, in unavoidable misalignment and in poor shop practices. Manufacturers of turning rolls can not rate their product on the basis of the worst possible application and supply power to meet such conditions as Figure 10. If they did, they could not be competitive in the price-conscious marketplace. To make a point, fabricators who know they are going to use the rolls under "unusual" vessels, must make an allowance for the "unusualness" and pay a little premium for a heavier Driver than the weight alone dictates; making sure there is extra horsepower at standard speed or slower speed at standard horsepower. If a job, such as Figure 10, comes along once in a while, the user can double the ratio of the primary drive (cut the speed in half) and get twice the power at the wheel O.D. but only if the turning rolls are basically rugged to begin with.

CENTER DISTANCE AFFECTS TRACTION AND TORQUE REQUIRED

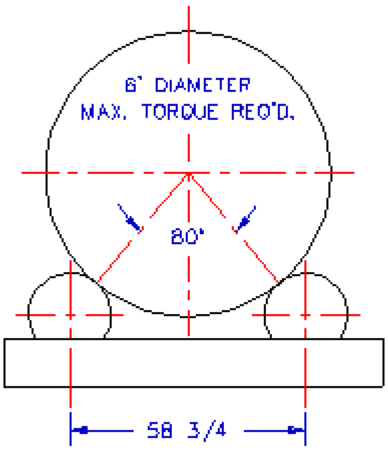


FIG. 11A - TRACTIVE VALUE 130

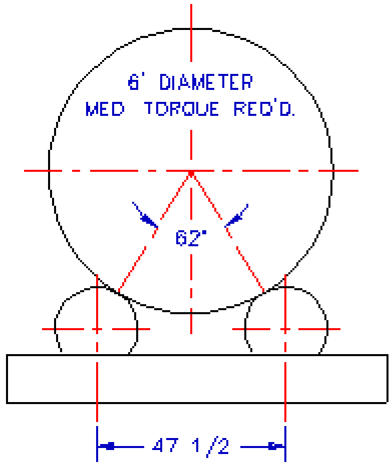


FIG. 11B - TRACTIVE VALUE 115

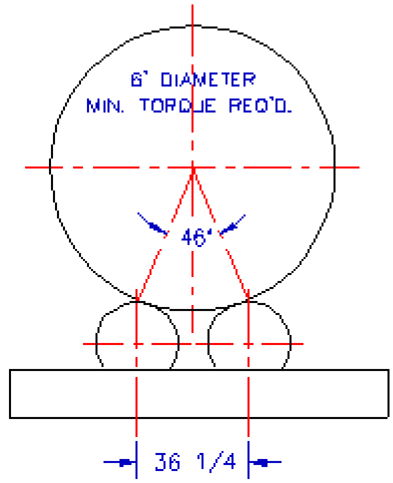


FIG. 11C - TRACTIVE VALUE 100

As shown in Figures 11A, B and C, a turning roll with adjustable center-distances will accommodate a given diameter vessel in more than one Center-Distance setting. For example, a PRESTON-EASTIN turning roll will cradle a 6-foot vessel in C-D settings of 36.25", 47.5" and 58.75". USE A SHORT CENTER DISTANCE WHENEVER POSSIBLE. Symmetrical, balanced vessels will safely cradle in contact angles between 45° and 60°.

Figure 11C's 36.25" C-D setting and 46° contact angle affords normal traction and minimum torque required. Figure 11B's 47.5" C-D has a contact angle of 62° and affords 15% more traction and a resulting increase in torque required. An unbalanced load, as shown in Figure 10, calls for maximum traction such as in Figure 11A, which also increases the torque required to rotate the vessel. Unless the vessel demands the added traction and power, it is a waste to thus overwork the rolls.

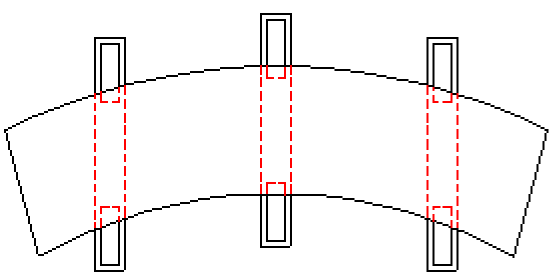


FIG. 11D - MISALIGNMENT, PLAN VIEW

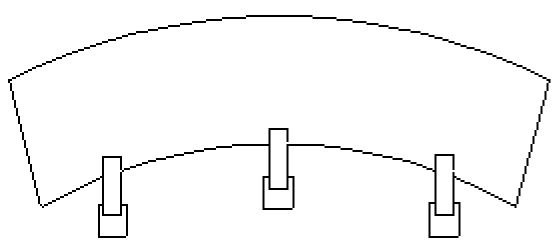


FIG. 11E - MISALIGNMENT, ELEVATION VIEW

Refer to Figures 11D and 11E. The magnitude of the power required to rotate a misaligned or bent-axis vessel can be demonstrated with a foot-long piece of 1/4" round steel rod. Make sure it is straight. Lay it on your desk and roll it with both hands flat down and with the rod between your hands and the desk. Rolls easily. Now put a slight arch-bend in it and try it again. Do not let either the ends, or the middle raise up off the desk. Now you find you are exerting a straightening force while you try to roll it...you are actually trying to cold work the rod.

Misalignment of turning rolls, Figures 11D and 11E, has the same resistance to rotation of the vessel as there was with the 1/4" rod. The greater the misalignment, the greater the rotation power required. When you try to rotate a vessel that is bent axis or misaligned, you are trying to cold-work the entire vessel.