Sumitomo Drive Technologies

TORQUE ARM DESIGN CONSIDERATIONS

FOR SHAFT-MOUNTED REDUCERS

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WHITE PAPER

Torque Arm Design Considerations for Shaft Mounted Speed Reducers

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Introduction

In the power transmission industry, shaft mounted speed reducers provide one possible solution to meet the speed reduction/power generation needs for an application. As the name implies, a Shaft Mounted Speed Reducer (also known more simply as SMSR) is a speed reducer mounted directly onto, and statically supported by, a driven shaft - that may be found on a conveyor. Typically, the SMSR incorporates a hollow bore (keyed, Taper-Grip® bushing, etc.) to facilitate mounting onto the driven shaft.

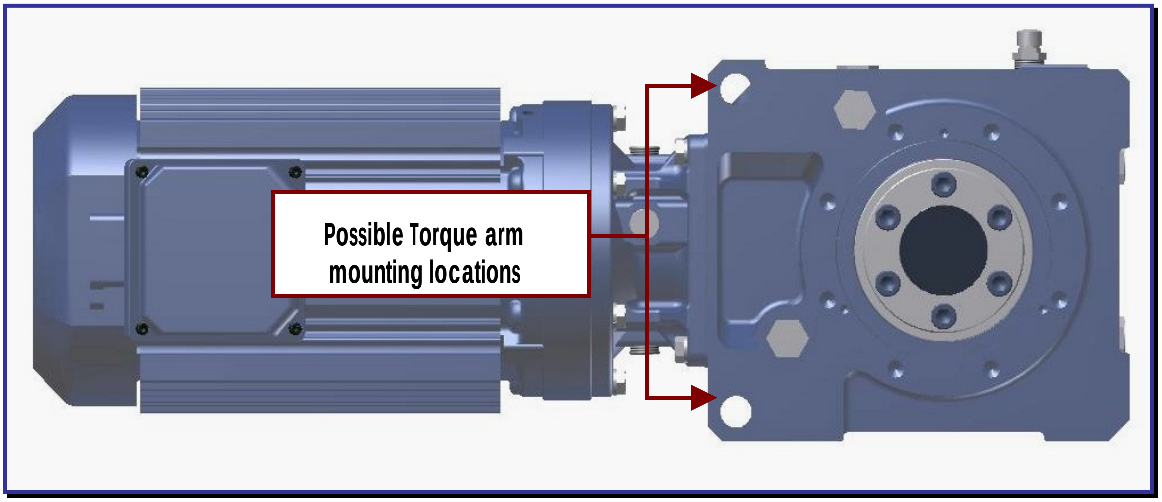
The SMSR may be "fixed" to the machine using an output flange or, in certain instances, its housing may be bolted directly onto the machine. However, situations exist where direct attachment of the SMSR is either not possible, or not desirable. In such situations, the SMSR is supported only by the shaft that it is intended to drive. When the SMSR is mounted directly onto a driven shaft with no other external support, it must have a torque arm attached to it. A torque arm is a pivoted connecting link between the reducer and a fixed anchor point intended to resist the torque developed by the reducer. Quite simply, a torque arm transmits the reaction torque produced by the SMSR into the structure of the machine, thereby preventing the counter-rotation of an SMSR during operation.

Most manufacturers of shaft mounted speed reducers have designed, and offered for purchase, standard torque arms for their products. Situations may exist, however where a manufacturers' torque arm does not meet the needs of a certain application (e.g. due to space limitations). In such situations, the machine designer may be required to design his/her own torque arm to fit within the constraints of their application. This paper provides some design guidelines for such a situation.

Resultant Force

In considering the design of a torque arm, first you need to understand the amount of load (or force) that the torque arm may see during unit operation. To determine this force, you need two pieces of critical information:

1. The torque capacity of the SMSR: As the name implies, this is the mechanical capacity (typically expressed in terms inch•pounds or Newton•meters) that the SMSR is capable of developing at its output. While it may be tempting to simply multiply the MOTOR output torque by the reducer's reduction ratio to obtain an output torque value, it is recommended to consider (at a minimum) the larger of the following values:
   i. the SMSR's output torque capacity (as listed in the product catalog) or,
   ii. the product of the motor's output torque and reduction ratio times an additional 2.5 – to take into account the motor's starting torque.
2. The dimensional location on the SMSR where the torque arm will be mounted: Manufacturers of shaft mounted speed reducers provide at least one mounting location for a torque arm. Note that the point where the torque arm attaches to the reducer (either directly or indirectly through a bracket) is known as the pivot point. Many manufacturers provide more than one potential location for the torque arm in order to accommodate the various mounting configurations available for a given product. The location(s) of these mounting holes/positions may be found in catalog cut sheets or through manufacturer-supplied product drawings. As seen in the following picture of a Sumitomo Cyclo® Bevel Buddybox, multiple mounting holes are available in the gear housing for placement of a torque arm:

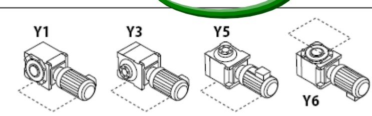


Using this Sumitomo Cyclo® Bevel Buddybox as an example, let's say you have an application that requires a bracket- style torque arm and this bracket will be attached to the housing at both identified mounting holes. Using the unit model size, reduction ratio, and motor input speed into the reducer, you can determine the output torque capacity from the reducer catalog ratings table (see the following illustration):

Sumitomo Drive Technologies Cyclo® BBB

Speed Reducers

60 Hz, 1750 RPM Frame Size Selection Tables



Single Reduction Y1, Y3, Y5, Y6 Mounting Positions

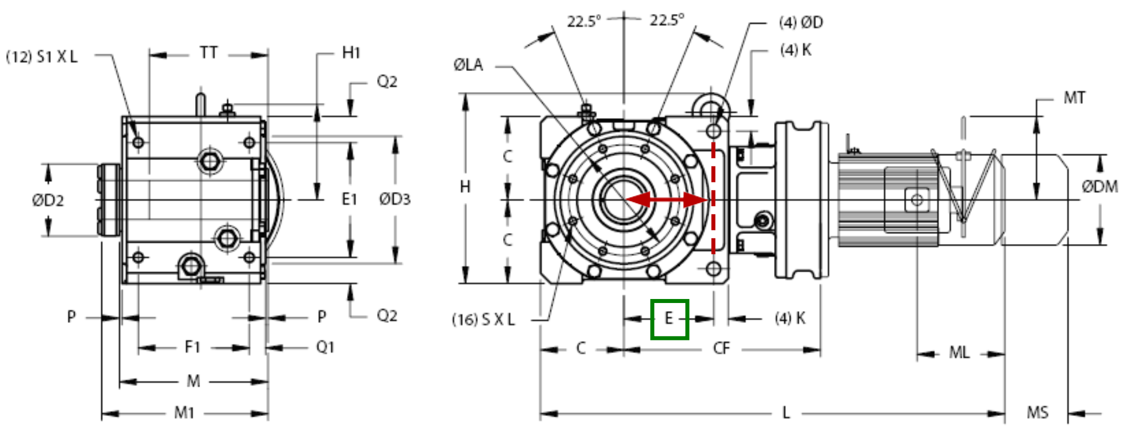
Dimensions on pages 2.22–2.23

Output RPM	19.9	17.2	14.2	11.6	9.8	8.45	7.03	5.74	Frame Size
Ratio	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	305	
Input HP	**1.70**	**1.62**	**1.31**	**1.05**	**0.75**	**0.69**	**0.58**	**0[illegible]58**	**3A100**
Output Torque (in•lbs)	4953	5461	5349	5248	4447	4735	4791	5[illegible]59	
Hollow Shaft OHL (lbs)	1120	1120	1120	1120	1120	1120	1120	1[illegible]20	
Solid Shaft OHL (lbs)	990	990	990	990	990	990	990	[illegible]0	
Input HP	**2.24**	**2.13**	**1.61**	**1.45**	**1.04**	**0.95**	**0.75**	**0[illegible]76**	**3A105**
Output Torque (in•lbs)	6527	7180	6574	7248	6166	6519	6195	7[illegible]77	
Hollow Shaft OHL (lbs)	1120	1120	1120	1120	1120	1120	1120	1[illegible]20	
Solid Shaft OHL (lbs)	990	990	990	990	990	990	990	[illegible]	
[illegible]	**2.56**	**2.55**	**2.01**	**1.74**	**1.27**	**1.15**	**0.90**	[illegible]	**3A110**
Output Torque (in•lbs)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8990	
[illegible]	1120	1120	1120	1120	1120	1120	1120	[illegible]	
Solid Shaft OHL (lbs)	990	990	990	990	990	990	990	990	
Input HP	**2.98**	**2.81**	**2.33**	**1.89**	**1.49**	**1.35**	**1.02**	**0.94**	**3A115**

You can also use the catalog dimension sheet to determine the location of the identified mounting holes relative to the center of the reducer's output bore:

Dimensions Gearmotors

Sumitomo Drive Technologies Cyclo® BBB



All dimensions are in inches.

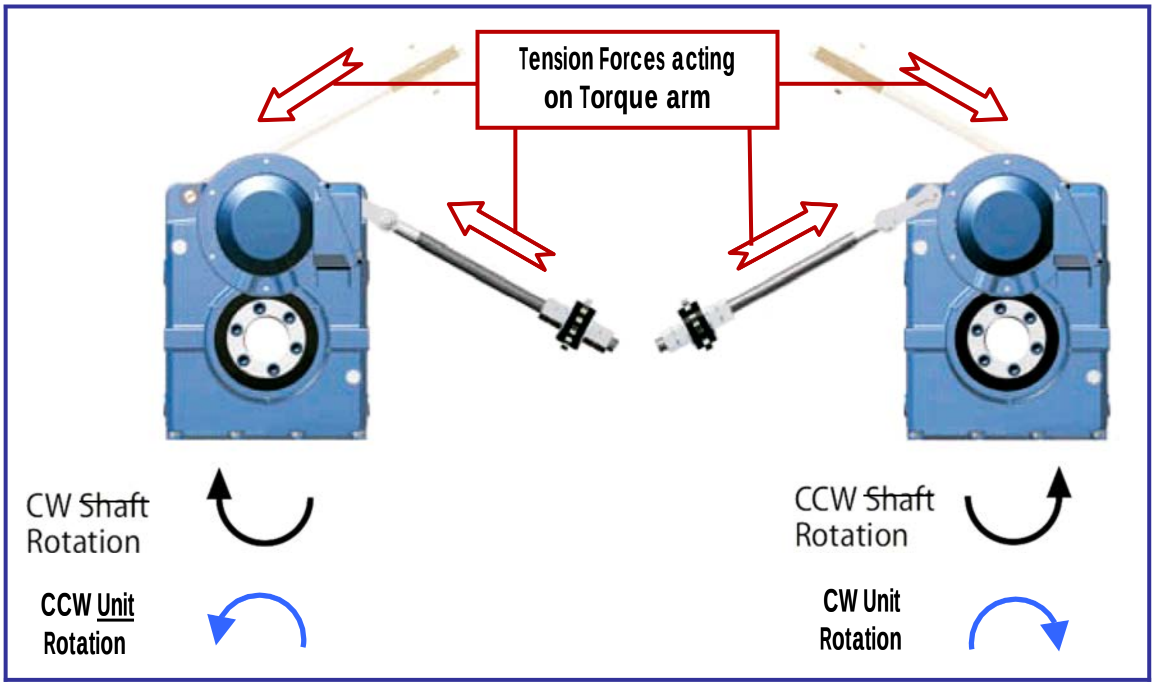
Model	CF	ØDC	C	E	F	K	Z	ØD	E1	F1	Q1	Q2	S1 x L
3A100, 3A105	9.33	5.91	4.33	4.49	7.24	0.71	1.38	0.71	5.91	6.30	0.91	1.38	M12 x 0.79
3A110, 3A115	9.76	6.38											
3A120, 3A125	9.57	8.03											
3A140, 3A145	10.43	9.06											

With this information, you can now calculate the force acting at the selected pivot point given the fact that Torque is the product of Force and Distance. You can determine the unknown force (F) using these formulas:

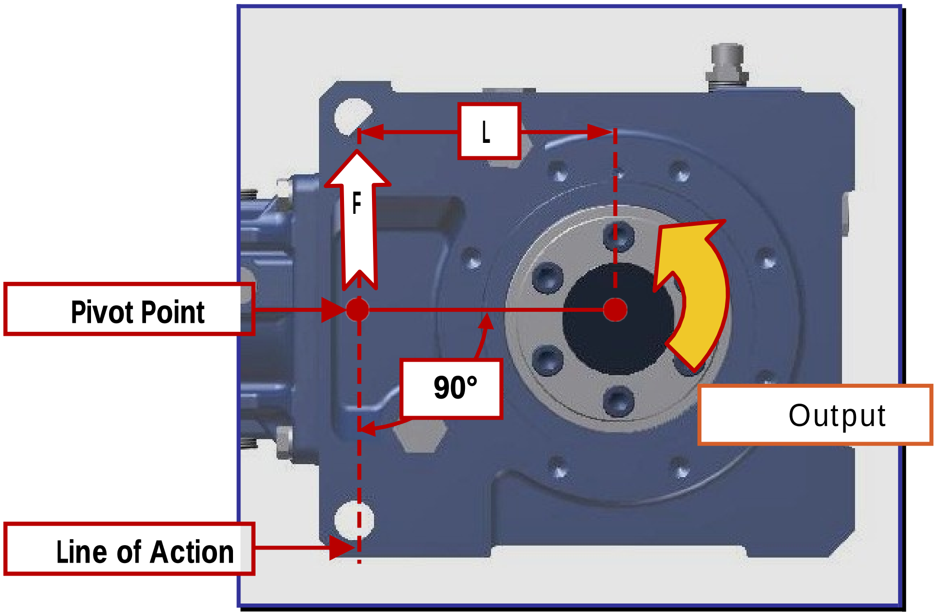
$$\text{Torque (T)} = \text{Force (F)} \cdot \text{Distance (L)}$$

$$F = \frac{T}{L}$$

It is important to note that during operation the SMSR will tend to rotate about the driven shaft in the direction opposite to that of the driven shaft's rotation. With this in mind, it is significant that the calculated force "F" (above) acts in pure tension on the torque arm. This fact is especially important for torque arms that are long in length because, if they are exposed to compressive forces, they may buckle. The following manual section for the Sumitomo Cyclo® Helical Buddybox shows the correct method of mounting a torque arm so that it is in tension:



In order to maintain pure tension loading for the torque arm, the pivot point of the torque arm should run along, or parallel to, the line of action. The line of action is defined as the right angle formed by a line joining the pivot point and the center of the SMSR's output bore.

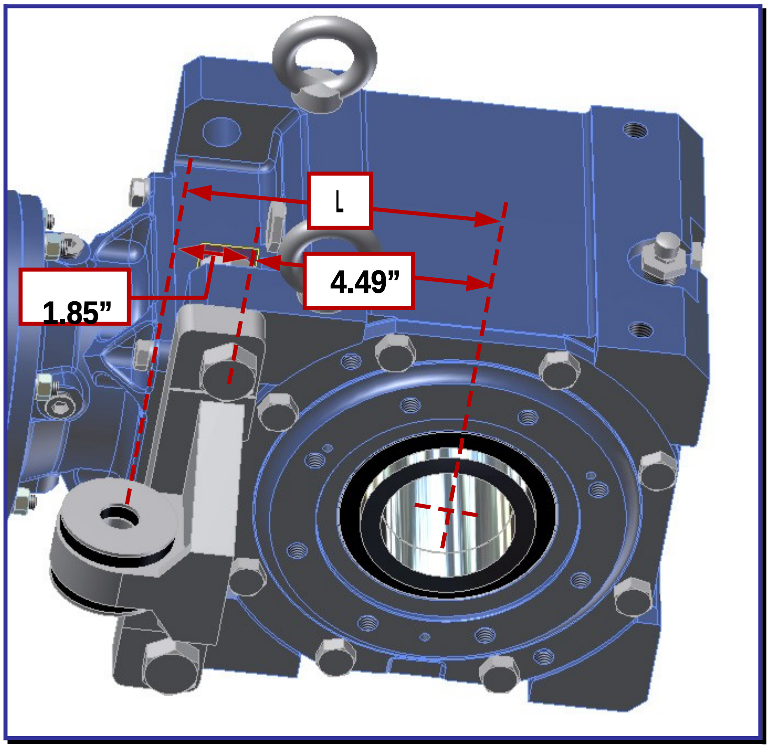


Using values from the Cyclo® Bevel Buddybox example, you can calculate the resultant force acting at the pivot point as follows:

$$T = (F)(L) \longrightarrow F = \frac{T}{L} = \frac{8{,}990 \text{ in}\cdot\text{lbs}}{4.49 \text{ in}} = 2{,}002 \text{ pounds}$$

In essence, the connection method at the pivot point you chose (i.e., bolt, threaded rod, etc.) must be able to withstand this calculated force when in tension. If you find that the calculated force exceeds the physical limits of the connection method, you may choose to incorporate a different, stronger material for the torque arm.

Another way to minimize this force is to increase the distance “L” of the pivot point. To illustrate this, the following picture shows the same Sumitomo Cyclo® Bevel Buddybox model used in the first example:



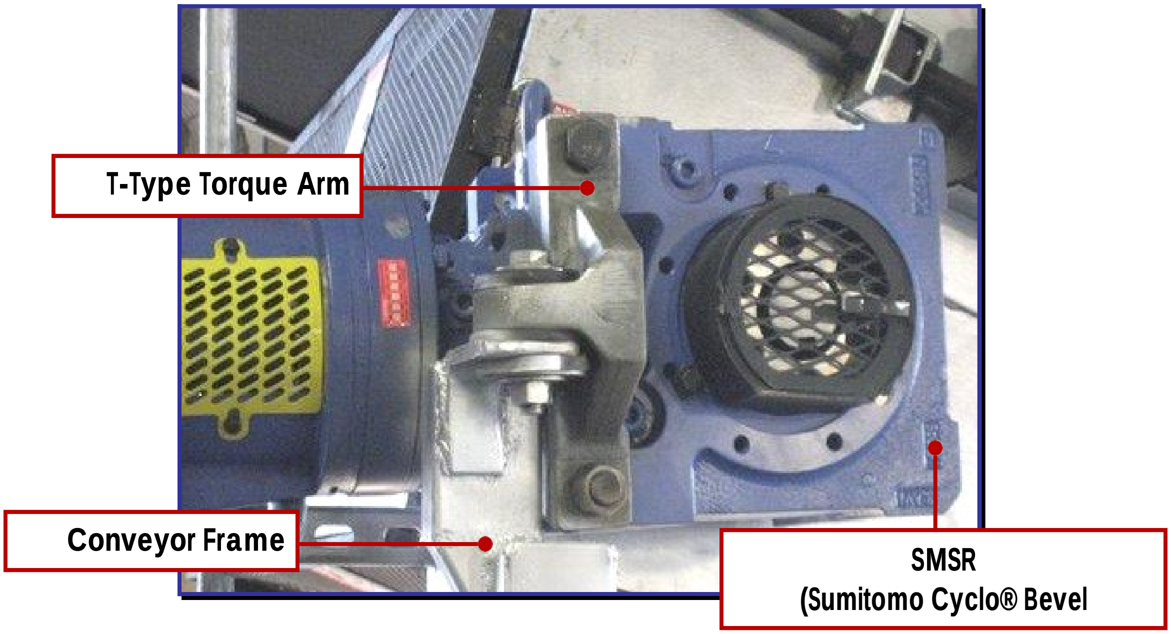
In this example, the reducer has a T-Type torque arm mounted to it that moves the pivot point an additional 1.85 inches further from the center of the reducer’s bore.

If all other factors remain the same, this increase in distance yields a decrease of nearly 600 pounds in the force on the torque arm:

$$T = (F)(L) \longrightarrow F = \frac{T}{L} = \frac{8{,}990 \text{ in} \cdot \text{lbs}}{(4.49 + 1.85)\text{in}} = 1{,}417 \text{ pounds}$$

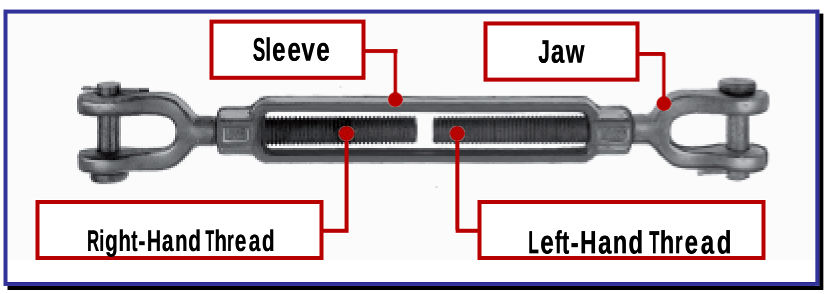
Once again, this calculated force must be compared to the yield stress of the torque arm material to assure that the material limitations are not exceeded.

The following photo shows a shaft mounted speed reducer (Sumitomo Cyclo® Bevel Buddybox) in a conveyor application utilizing a “T-Type” torque arm:

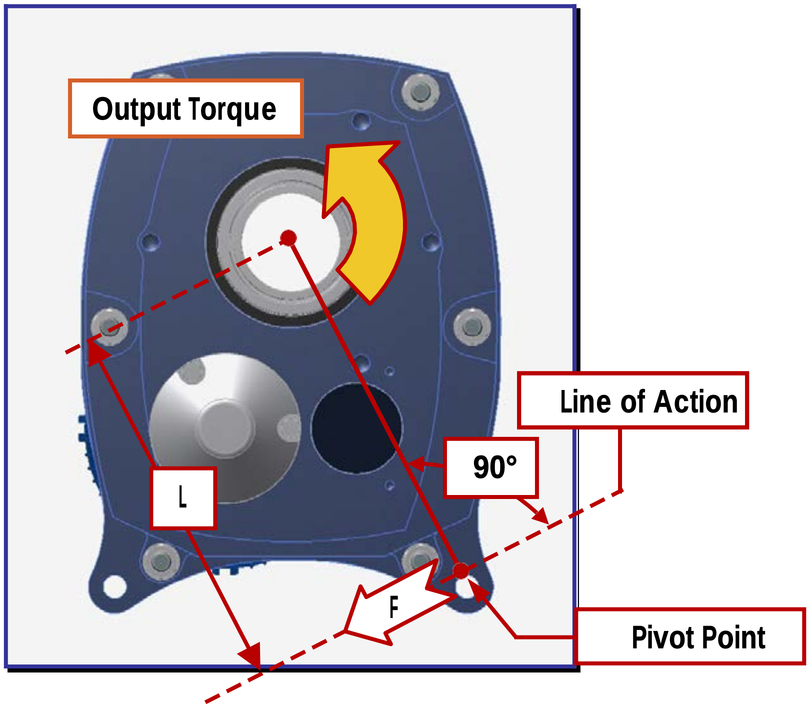


A Turnbuckle for a Torque Arm

Provided that it will fit within the design constraints of your application, you may opt to use a turnbuckle for a torque arm. A turnbuckle is a device commonly used to tighten a rod or rope. Its components include a sleeve with screwed connections of opposite hands (left and right) at each end. Upon turning the sleeve, the connected parts (threaded rods) will be drawn together, taking up slack and producing tension.



You can calculate the force acting at the pivot point in this situation using the same formula for Force. The following Sumitomo HSM I illustration depicts this process:



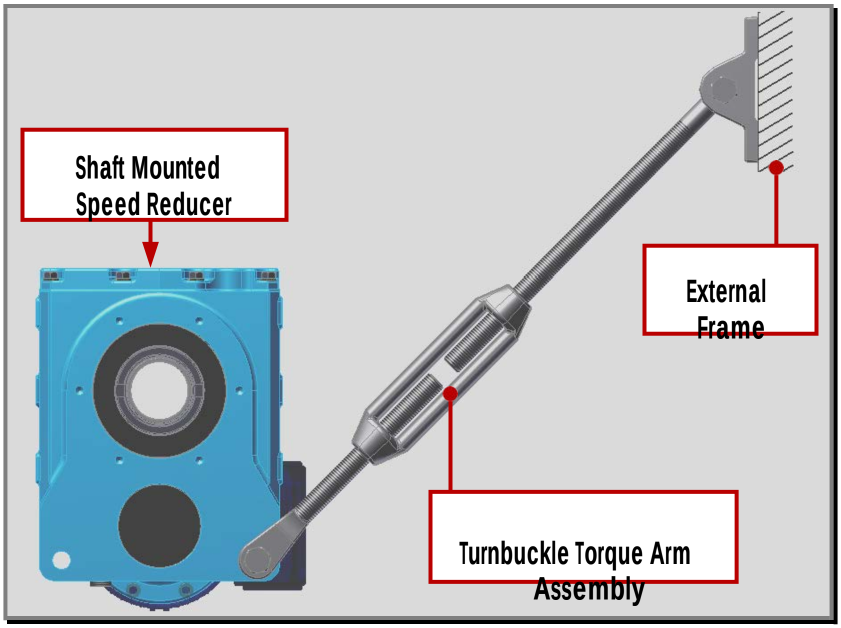
Once again, it is important to determine the force (F) in order to assure that this force will not exceed the physical limitations of the torque arm material. This force is calculated as follows:

$$F = \frac{T}{L}$$

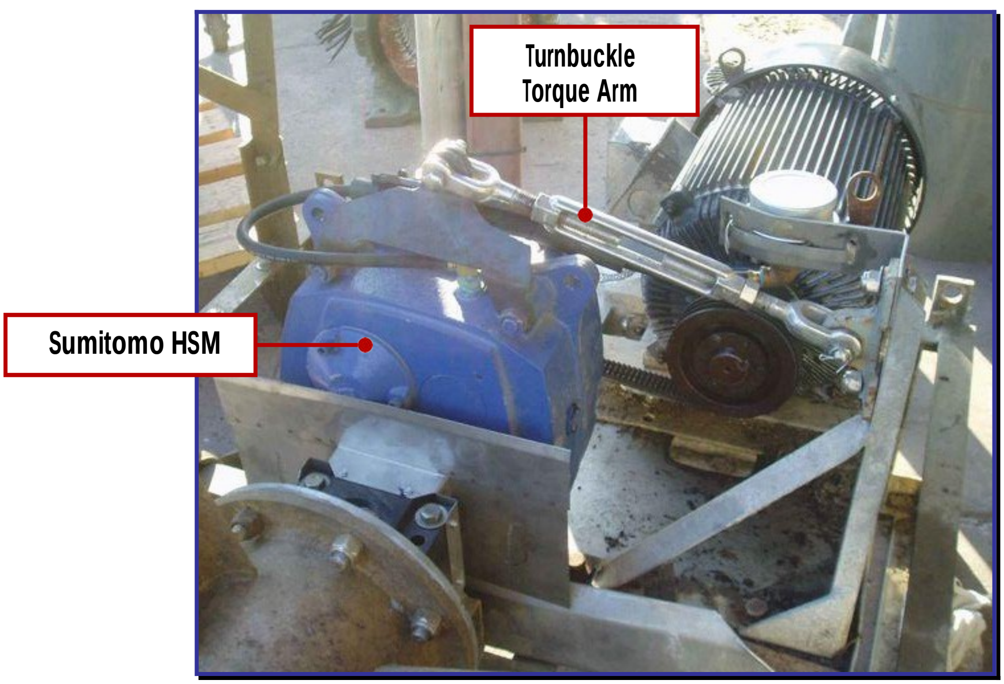
where:

"T" = the output torque (capacity) of the SMSR [typically expressed as in•lbs or N•m]
"L" = the distance from the center of the output bore to the center of the pivot point [in, m].

This picture depicting a Sumitomo Cyclo® Helical Buddybox illustrates the typical mounting style for a turnbuckle torque arm:



The following application photo shows a Sumitomo Helical Shaft Mount (HSM) unit using a turnbuckle type torque arm:



A Note about Mounting Hardware

In addition to assuring that the forces acting on the torque arm itself do no exceed the limitations of the torque arm material, you must also consider the effects of the force on the mounting hardware (nuts, bolts, etc.).

When taking this into account, you must note that the force is not acting on the hardware in tension, but rather in shear. Depending on the location of such hardware, bending movements induced by the force may also be acting on the hardware.

Hardware manufactures usually provide yield and shear limitations for their product. Once again, it is important to compare the calculated forces/stresses acting on the hardware against the published limiting values to assure that the critical points are not exceeded.

A Note about Reversing Rotation

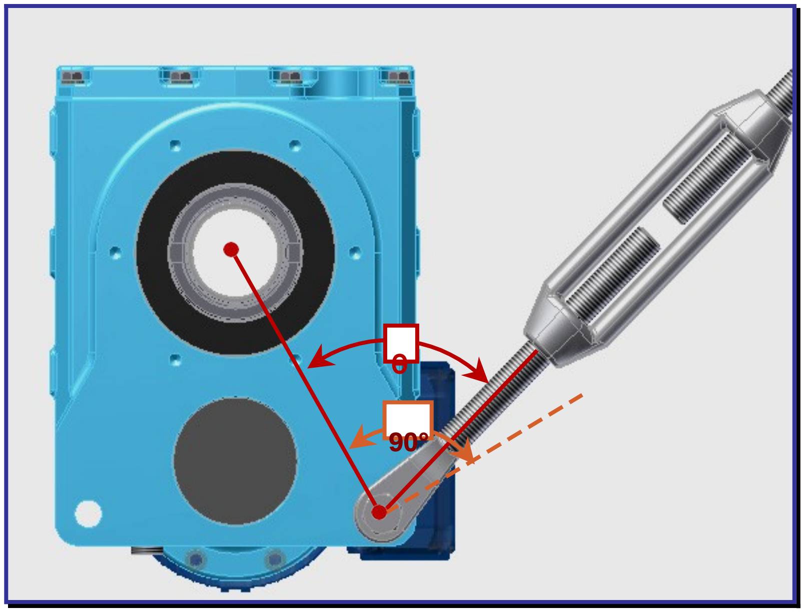
In reversing applications, the output of the SMSR rotates in one direction for a period of time, and then reverses and rotates in the opposite direction for a period of time. This application type requires considering the compressive forces that the torque arm must also bear.

Recalling that ideally a torque arm is mounted so it is in tension, in a reversing application, the torque arm may see a period of time when it also receives compressive forces. Such compressive forces, if great enough, could buckle the torque arm – such as the turnbuckle torque arm discussed previously. For such applications, designers may want to add a second torque arm on the opposite side of the SMSR. The second torque arm would take the tension forces generated by the reverse rotation while minimizing the compressive forces on the first torque arm.

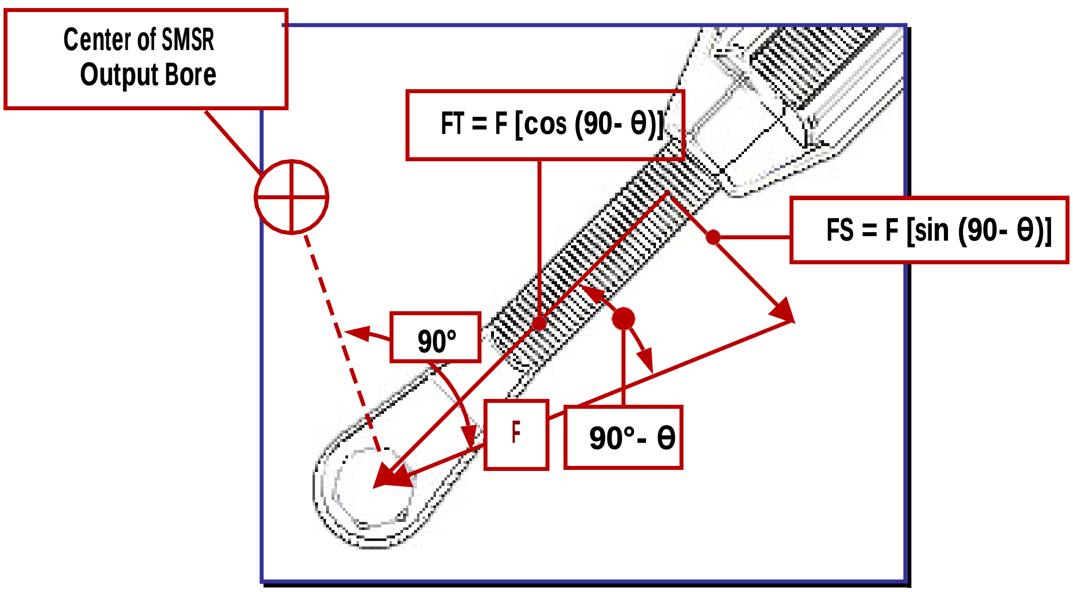
Angles other than 90°

Although it is important to maintain a pivot point at 90° to the center of the SMSR output hub, it may not always be possible due to limitations in the machine onto which the SMSR will be mounted. This is not uncommon and reducer manufacturers who supply turnbuckle torque arms with their SMSR units note that the torque arm may be mounted with an angular variation of ±15°.

In such situations, the designer needs to evaluate the effects of the resultant forces acting on the torque arm. In the following illustration, the torque arm is mounted to the Sumitomo Cyclo® Helical Buddybox at some angle (θ) that is less than 90°:



Because the torque arm is not acting at a 90° angle to the output bore of the SMSR, there are two forces acting on it. The following free-body diagram details these forces:

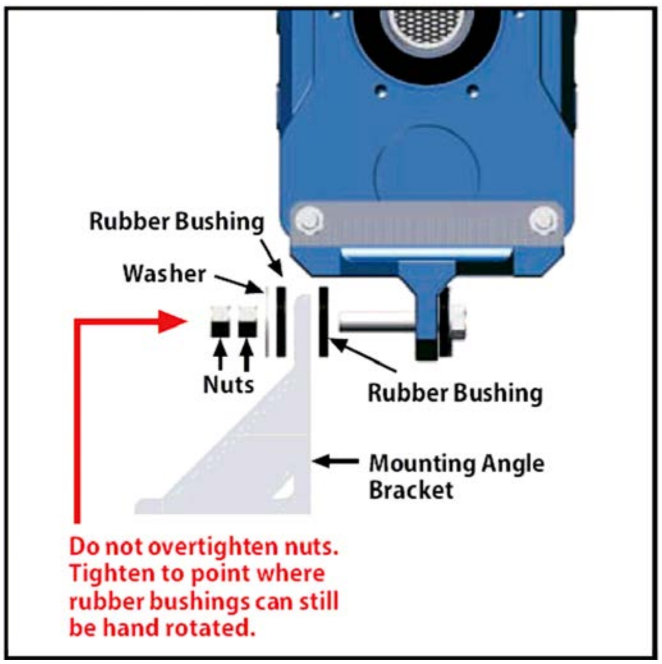


The resultant forces (FT and FS) are the component forces of Force "F" acting on the torque arm. These resultant forces place not only a force in tension (FT) acting on the torque arm, but also a shear force (FS). Both forces must be considered when evaluating the strength of the torque arm design.

The Effect of Shaft Runout

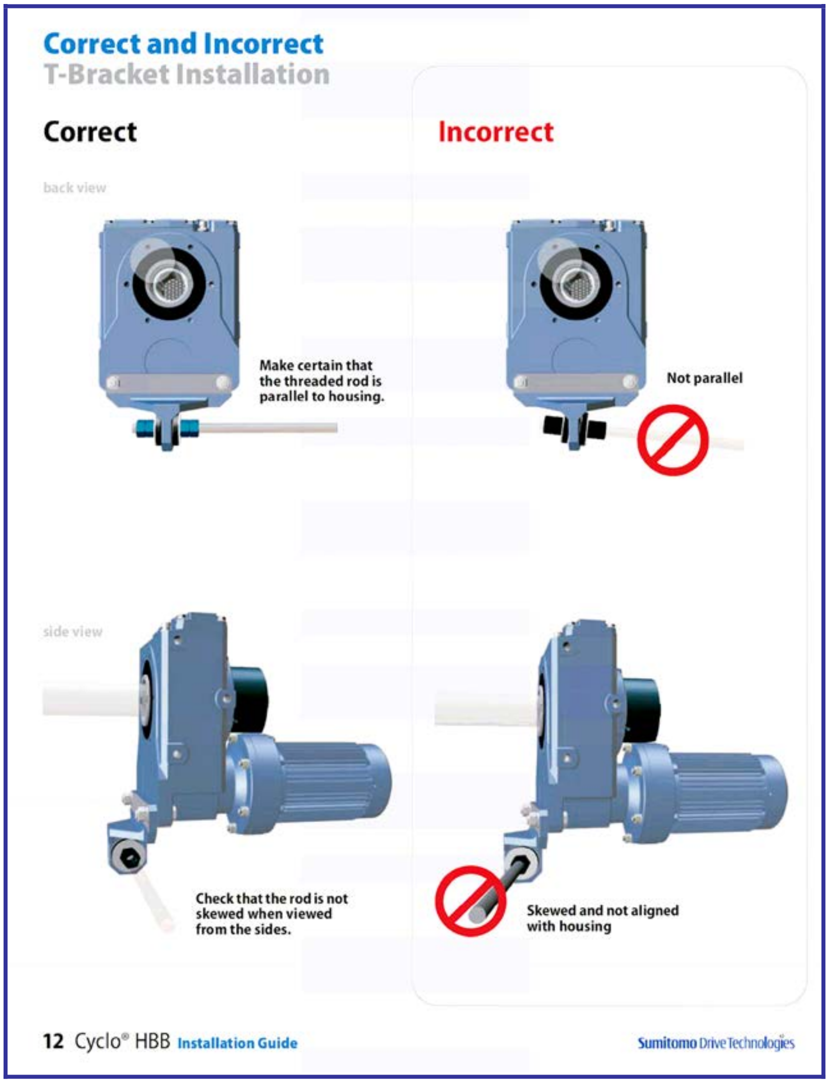
Despite a high degree of accuracy in manufacturing processes, shaft runout may have negative consequences on a shaft mounted speed reducer. Such runout (on the driven shaft) may cause the reducer to "wobble" on the shaft during operation. This could be particularly troublesome if the torque arm is rigidly mounted to the anchor point. A rigidly mounted torque arm attached to a SMSR driving a shaft with a high degree of runout may result in (among other things): a broken driven shaft, cracks at the anchor point, a decrease in the life of the output bearings of the SMSR and/or the conveyor, and lubrication leakage. Introducing some "float" in the torque arm at the anchor point will counteract these problems.

Float may be introduced at the pivot point by attaching rubber bushings to the pivot and anchor points. See the following Sumitomo Cyclo® Helical Buddybox torque arm mounting design as an example:



A designed loose clearance between the bolts and the through holes in the torque arm bracket may also assist in creating this float.

In addition to taking precautions to eliminate a rigid mount, designers must also ensure that the torque arm is properly aligned when mounting it to the SMSR. Misalignment may inadvertently cause binding that could decrease or entirely eliminate this float. The following manual sheet from the Sumitomo Cyclo® Helical Buddybox illustrates proper torque arm alignment:



If dual rotation of the output shaft is possible in the application, manufacturers recommend installing rubber bushings on both sides of the pivot and anchor points so float is possible regardless of the direction of rotation.

Conclusion

Although seemingly simple in concept, a torque arm is an important component when considering a shaft mounted speed reducer for an application. Before selecting a potential torque arm design, designers should evaluate the offering supplied by the manufacturer of the shaft mounted speed reducer. In doing so, they may determine that the standard offering fits into the application constraints. Additionally, some manufacturers, such as Sumitomo Drive Technologies, offer more than one standard design (i.e., Turnbuckle, T-Type) to meet a variety of applications. However, if the existing available designs fail to meet the established application criteria, following the methodology detailed in this paper will help to develop a functional and robust torque arm design.

January 2007 Todd Bobak

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