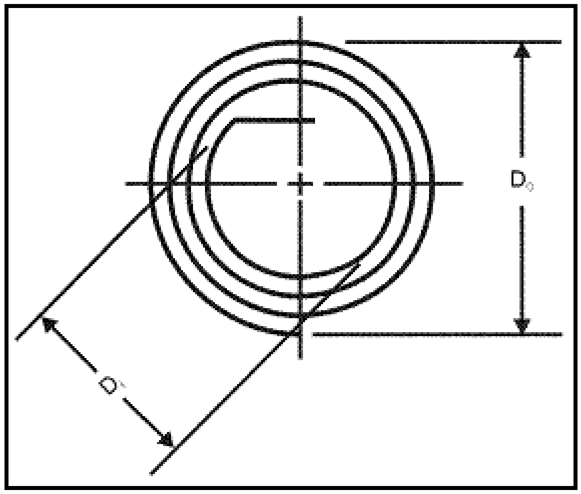
Advanced Spring Design Software Notes: Spiral Torsion Springs

The ASD software includes a program for spiral torsion springs, also known as brush springs or hair springs. This document supplements the content in the SMI Encyclopedia on this spring type, with an emphasis on how to interact with the software and interpret results.



Materials and Strengths

ASD provides a selection of possible materials as well as three levels of strengths – moderate, high, and extra high. The resulting tensile strength estimate is based on SMI Encyclopedia Figures SM-4 and SM-6, as well as Table SM-12. There is typically very little difference between the moderate and high strength estimates while the extra high strength option results in significantly higher tensile strength. The tensile strength value can be overwritten if you have your own tensile strength data.

Critical Values and Ratios

The SMI Encyclopedia indicates that deflections of greater than 2 or 3 turns can cause “caging” where the coils buckle into a ball. The ratio of the strip width to thickness should be from 3 to 15. The ratio of strip length to thickness should be from 200 to 3000 with smaller ratios typically associated with brush spring designs involving smaller deflections.

SMI Equation PS-21 for Arbor Size Estimation

The SMI Encyclopedia states the following…

Selecting an arbor diameter to determine space requirements for a brush spring is complex. The task is made easier by use of:

$$\theta \cong \frac{\sqrt{D_a^{\,2} + 1.27Lt} - D_a}{2t} - \frac{2L}{\pi(OD + D_a)} \qquad \text{(PS-21)}$$

This approximation assumes that coils are spaced uniformly in the free position.

This is a curious equation, apparently relating a sample deflection value (theta) with the spring geometry but completely ignoring torque. Fortunately, with ASD's ability to solve systems of nonlinear equations, this formula isn't necessary for computing the arbor size. Older versions of ASD activated this equation if an assumption was made that the coils were equally spaced but it's not clear that the equation is valid so it has been removed from the current version.

Scenario 1: Strip Cross-Section Geometry

The ASD program includes a variable called Torque to Set. If the strip material is loaded with more than that amount of torque, the strip would be overstressed and could take a set, not returning all the way to the original free position when the load is removed. For a given material, Torque to Set is a function of the strip cross-section dimensions – axial width (b) and radial thickness (t). According to SMI, the width-to-thickness ratio b/t should be kept within a range of 3:1 to 15:1.

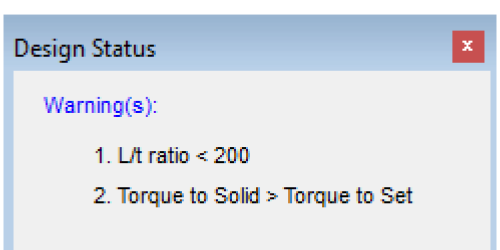
ASD allows you to input any two of these three variables and it will solve for the third. For these examples, Medium Carbon 1050 with Strip Strength High is used. Input b=0.5" and t=0.042" and ASD computes Torque to Set as 21.643 lbf-in. Suppose you have an application that requires a torque of about 16 lbf-in. You have space for roughly half an inch axially. What strip thickness would be needed? You could give yourself a little safety buffer and input Torque to Set as 17.6 – a 10% cushion. Then an input of b=0.5" results in a strip thickness of 0.0376". So that would be the minimum thickness that might be used. Larger t values would result in a heavier, stronger spring but may also require more space radially.

Scenario 2: Strip Geometry Plus Coil Diameters

The Arbor Diameter (Di) and Min. Free Diameter (Do) create an envelope for the coiled strips. If Di=0.25" and Do=1.0", that leaves 0.375" for the cumulative thickness of the coiled strip. So how many coils can we squeeze between the arbor and the outside? That's a function of the strip thickness (t) and the number of coils. Given t=0.056, the maximum number of coils possible would be 0.375/0.056 = 6.7. but that would be if they were tightly wound. A spiral torsion spring needs some space between the coils to do its work.

We can use the "% of Fill Area" variable in the ASD program to investigate different possible designs. For example, if the % is input as 50, that means that half the area is filled by the strip coils. Try this example: Strip Material is Stainless 301 Full Hard. Strip Strength is Extra High. Di=0.25", Do=1.0", b=0.375", t=0.056", and %Fill=50.

ASD computes the free coils as 3.3482 and the Turns to Solid as 0.9274. The torque to solid is significantly more than the torque to set so unless something is done to prevent the mechanism from excessive deflection, this spring could easily be overstressed.

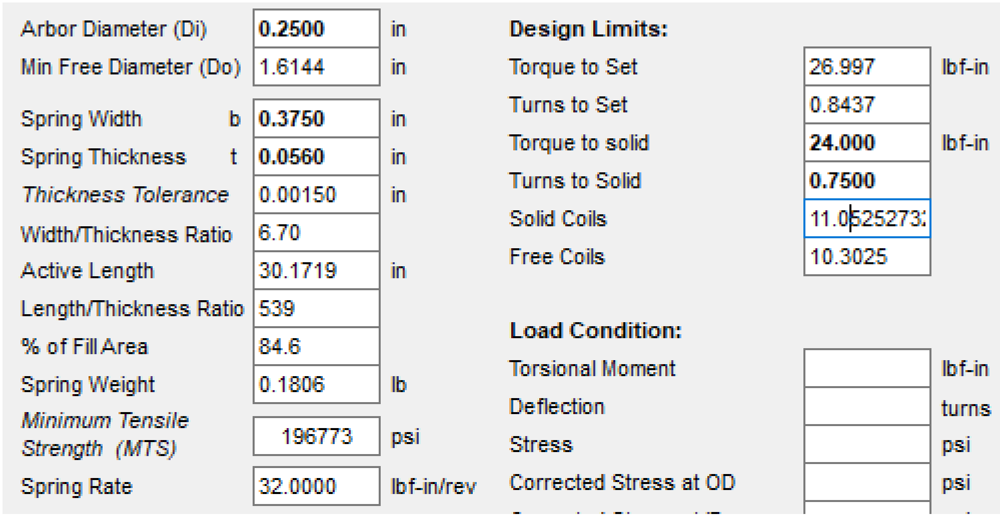


Arbor Diameter (Di)	**0.2500**	in	**Design Limits:**		
Min Free Diameter (Do)	**1.0000**	in	Torque to Set	26.997	lbf-in
Spring Width b	**0.3750**	in	Turns to Set	0.1838	
Spring Thickness t	**0.0560**	in	Torque to solid	136.200	lbf-in
Thickness Tolerance	0.00150	in	Turns to Solid	0.9274	
Width/Thickness Ratio	6.70		Solid Coils	4.27561595	
Active Length	6.5742	in	Free Coils	3.3482	
Length/Thickness Ratio	117				
% of Fill Area	**50.0**		**Load Condition:**		
Spring Weight	0.0393	lb	Torsional Moment		lbf-in
Minimum Tensile Strength (MTS)	196773	psi	Deflection		turns
			Stress		psi
Spring Rate	146.8618	lbf-in/rev	Corrected Stress at OD		psi

We can work this another direction, with an input for torque to solid instead of % of Fill. An input of 24 lbf-in for Torque to Solid would keep the spring from being overstressed. This spring has more coils and can only deflect a little over a quarter turn.

Arbor Diameter (Di)	**0.2500**	in	**Design Limits:**		
Min Free Diameter (Do)	**1.0000**	in	Torque to Set	26.997	lbf-in
Spring Width b	**0.3750**	in	Turns to Set	0.3234	
Spring Thickness t	**0.0560**	in	Torque to solid	**24.000**	lbf-in
Thickness Tolerance	0.00150	in	Turns to Solid	0.2875	
Width/Thickness Ratio	6.70		Solid Coils	6.17704857	
Active Length	11.5642	in	Free Coils	5.8896	
Length/Thickness Ratio	207				
% of Fill Area	88.0		**Load Condition:**		
Spring Weight	0.0692	lb	Torsional Moment		lbf-in
Minimum Tensile Strength (MTS)	196773	psi	Deflection		turns
			Stress		psi
Spring Rate	83.4905	lbf-in/rev	Corrected Stress at OD		psi

Suppose you need more turns and wonder how much bigger Do must get. Input Turns to Solid as 0.75 and blank the Do value. Do increases from 1.0 to 1.6144, the number of coils are nearly doubled, and the weight is nearly tripled.



Scenario 3: Required Torque and Deflection with a Given Arbor Size and Spring Width

Designing from function instead of from strip geometry seems practical. In this example, Strip Material Stainless 301 Full Hard with Strip Strength Extra High is used. Assume an arbor (ID) of 0.25, a spring width of 0.375, torque=10 and deflection=0.5. The spring rate is computed as 20 but there isn't enough information provided to compute the outer diameter or strip thickness.

We know that we need the spring to handle at least 10 lbf-in of torque, so if we input Torque to Set=12, that would provide some cushion in keeping the spring from being overstressed. The strip thickness is computed as 0.0353. Checking with a supplier, the closest strip size available is 0.035. So we input that for t and blank the Torque to Set which is then computed as 11.83 at 0.5915 turns.

Input a turns to solid value of 0.55 to complete the design. That value is greater than the 0.5 deflection but less than the turns to set. The Do value is computed as 0.8485.

In summary…

Turns or Torque to Set is a function of the strip cross section (b, t).

Turns or Torque to Solid is a function of the spring rate and the space available (Di, Do, t).