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Discussion Paper

Hollow versus Solid Swaybars

Comparison of the 2 separate design strategies and how they differ in practical use and manufacture.

by

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Comparison of Hollow and Solid Swaybar Design

In this paper the differences between solid and tube swaybars will be discussed. Namely in the stress distribution under load, weight differences and solid tube equivalents.

The reason why tube is chosen over solid is for weight. Although for a one-piece design it is harder to implement. Through searching for examples of hollow swaybars I have found the most sound design to be that of a series 5 RX7 (93 – 01), where a tube is used as the bar and blades are attached by splines. These are the only ones that I found I could get ID and OD dimensions, most manufacturers just give OD and state they are hollow. Generally they are of imperial sizes, and most have common imperial wall thickness.

Assuming that bar rate is only effected by the torsional member or the bar (blades are stiff) then the rate can be calculated and an equivalent solid found. The following page shows typical OD and wall of tubes, solid equivalent, % solid OD to tube OD, and % weight increase by going to solid bar.

For example a 31.75mm (1¼ “) by 1.24mm (0.049”) tube bar is the equivalent of a 23.0mm solid bar, this solid bar has an OD which is 72.6% (23/31.75 x 100) of the tube OD, and an increase in weight of 71.5% over the tube bar.
Another example is a 25.4mm by 6.35mm tube will act like a 25.0 mm solid bar as in torsion and bending (swaybar).

The sizes have been gained from a RACEtech stock list from British International Trading which deal in high strength materials such as “chromoly” and “aircraft grade aluminium” with all sizes coming in common imperial measurement.

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Comparison of solid and tube torsion members with equal outside diameters

The strength of these members, be it the ultimate strength, yield strength or fatigue strength depends on the maximum stress seen in the material. In a torsion member (and similarly for the same member under bending) the stress in the material depends heavily on the geometric shape. The stress (shear) that is found throughout the member under torque is given by the following formula:

$$\tau = \frac{Tr}{I_p}$$

Where τ = Shear stress.

T = Torque.
R = Radius from center.
Ip = Polar moment of inertia (geometry)

$$I_p = \frac{\pi \times \left(D_o^4 - D_i^4\right)}{32}$$

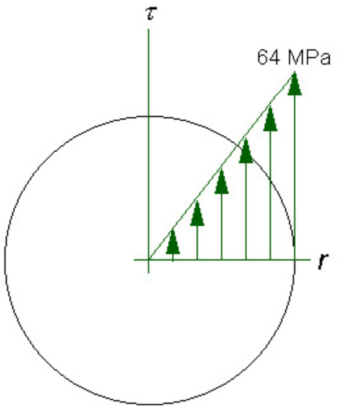
Where D = Diameter (inside and outside, inside = 0 for solid)

From the above equations can see that the outside of the member will have the largest stress. The absolute stress value also depends on the Ip, the bigger Ip (or diameter of the member) the smaller the stress will be. Again this Ip value depends on the diameter to the power of 4, this means only a slight increase in diameter can give a large increase in the Ip.

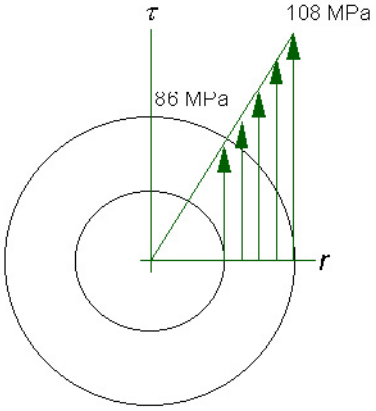
As an example, consider the following bars - Solid 20mm and a tube 20mm OD 16mm ID (2mm Wall).
Both under a torque load of 100 Nm. Using the above equations the following stress is calculated:

	Solid	Tube	
OD	20	20	mm
ID	0	16	mm
Ip	15708	9274	mm^4
Torque	100	100	Nm
Stress at OD	64	108	Mpa
Stress at ID	0	86	Mpa

Graphically the stress distribution across the radius of the members is as follows:



Solid Member



Tube Member

The figure shows graphically how the outer layers of the members carry the most stress. This can make the tube member more susceptible to failure due to surface or wall imperfections and damage.
Also, the figure shows how the tube member, with a reduced Ip, has a higher maximum shear stress at the OD (directly proportional to the Ip).

Therefore to conclude the solid member will be the stronger of the two in this case, as it has a lower overall shear stress.

Although in the above example the tube member had a higher peak stress level due to the lower Ip, the result would be the same if the two had the same Ip and different dimensions. This is because the tube would need to have a larger OD than the solid to match the solid Ip value. Having a larger outside diameter (and radius) the peak stress will be higher.

Special attention during manufacture

Because of torsion member's being heavily dependent on the outside diameter, constant geometric shape is required. This can be harder to achieve in tube materials than in solid materials. Usually requiring the use of a filler material so not to crush the tube while in the bending process. Reliable hand manufacture of these types of swaybars is next to impossible, the use of mandrels to bend the tube becomes essential.

Attachment of links to blades

The attachment of the swaybar links to the blades can be tricky in this design. In thin walled tube it may be possible to use a sleeve, clamping or gripping the tube to hold the correct distance from the bar. This design has been used, however it does suffer from the possibility of slip. Another method that has been used is to crush the tube into a vertical flat plate and drill holes through this. This can subject to the thin plate to excessive stresses and buckling if not designed carefully (the bar that this was used on had a very long blade and only 2 close adjustment holes at the end, this minimised the bending moment through the crushed tube plate). It also limits how much adjustment can be included in the bar.

Weight difference and unsprung weight effect

Assuming that a tube replacement swaybar can sustain the loads imposed on it, it can bring a reduction to the overall weight of the vehicle and the unsprung weight.
As an example taking a simple U type generic swaybar, with a blade length of 300mm, a bar length of 1100mm and a diameter of 24mm solid, using this with an equivalent tube with a wall of about 4mm. The following reductions in weight are possible:

	Solid	Tube	
Bar Length	1100	1100	mm
Blade Length	300	300	mm
Bar OD	24	25.4	mm
Bar ID	0	3.96	mm
Total Volume	769062	453439	mm^3
Total Weight	6.060	3.573	kg
Unsprung Vol.	67858	40009	mm^3
Unsprung Weight	0.535	0.315	kg
Weight Red.	2.487	Kg	
Unsprung Weight Red.	0.219	Kg	
% Weight Red.	41	%	
% Unsprung Weight Red.	41	%	

The actual reduction in unsprung mass is slightly more than what is stated in the above table. The table only calculates half the mass of the blade, which is what is calculated when measuring the unsprung mass due to suspension links. However during the suspension action the swaybar is rotated in its bushes, this rotation also has a weight effect. However rotation about its axis requires very little energy and will not impact the result heavily, therefore in this general discussion it will be emitted. For a more detailed look and measure of the unsprung mass, this weight would be included.

The table shows that a 40% reduction in weight can be achieved in this example, although this is only 2.5kg in total weight and 220g at each wheel. Conservatively assuming an unsprung mass of 20kg, this gives a decrease of only 1%, which is not a large amount.

The actual amount of reduction in weight is a function of the wall thickness to tube diameter ratio (or percentage). The thinner the wall compared to tube outside diameter the larger the weight reduction will be for an equivalent solid bar. The following table shows how for a thinner wall to tube OD ratio the higher the increase in weight for an equivalent solid bar.

Wall as % of OD	7.5	10.0	12.5	15.0	17.5	20.0	22.5	25.0
Solid OD as % of Tube OD	83.1	87.7	90.9	93.4	95.2	96.6	97.6	98.4
Increase in Solid Weight %	59.9	53.1	47.1	41.5	36.3	31.4	26.8	22.5

Therefore to maximise the weight effect of a tube swaybar, one must be chosen with the thinnest wall with the desired rate. Most tubes come in the ratio of between 12.5% and 25%.
The first table on the second page also shows weight increases from tube to solid for some common sizes.

Conclusion

Tube torsion members can be used successfully as swaybars with some benefit in weight reduction.
As an example, 2 individual, rate equivalent (approximately), common sized generic bars 1100mm long with 300mm blades, one solid 24mm the other tube of 25.4 x 3.96mm (1" x 0.156") gives a weight reduction of about 2.5kg with about 200g of that as unsprung mass per wheel.

However the downside to these is the increase in stress levels for equal OD or rate, and therefore reduced strength. Also the complications seen in manufacture swaybars from tubular medium, and the importance of geometric control under bending make these more difficult and expensive to make. The attachment points at the blades can also be a problem with these swaybar designs.

The additional complications and downsides of hollow bars seem to outweigh their advantage in overall weight and unsprung mass, which can be seen to only be marginal in street car application. Even OE manufacturers rarely use this type of design in their swaybars. However with the right conditions and setups, they can bring some gain in racing situations, which can require weight reductions to the gram.