

► Another Spider Article

By Steve Mowry

There are several inherent problems with treated cloth spiders which relate to both material properties and manufacturing process. The spider is a significant limiting factor regarding the performance of most transducers. Having designed many spiders and having written many transducer product specifications and test specifications, I know that the typical inherent variability of the spider stiffness/compliance over a large sample is $\pm 20\%$, but this is just a symptom of the problems. I will take another look at this simple but often-misunderstood component, the spider.

SPIDER PROBLEMS

First, a cloth spider—whether it is cotton, nomex, polyester, acrylic, or a combination of these—is made up of woven fibers. The first problem is that the material properties of a common cloth spider are not isotropic; they are orthotropic and vary in the x , y directions. However, during the spider manufacturing process the material orientation is typically random and the forming and cutting tools are axisymmetric. They do not require orientation. Thus any attempt to identify the orthotropic material properties (two dimensional) is not helpful. Due to the random orientation of the cloth, the material properties must be assumed isotropic.

Treated cloth is made up of woven fibers and chemicals with air being a significant displacer of volume within the cloth spider structure. Which brings up the second problem: The cloth spider is lossy and this inherent loss results in hysteretic behavior with respect to reaction force versus displacement. Hysteretic refers to changing behavior of the spider, not just versus displacement but also the direction of the displacement (**Fig. 1**).

The fact of the matter is that in a general sense and ideally, the mechanical damping coefficient $Q_{ms}(\pm x)$ would be infinite, with no mechanical losses. All damping would come from the motor, $Q_{es}(\pm x)$. However, this is impossible without some kind of maglev or other lossless suspension. The measurement plotted in **Fig. 1** illustrates that the spider has memory, $X(x)$ (mm).

It is generally accepted that a spider's stiffness/compliance will change by at least 15% over the useful life of the product

(warranty period). This is problem number three, and its cause is obvious. The material properties in cloth spiders change with time.

Perhaps the spider characteristic of most concern is the nonlinear nature of the spider's reaction force versus large displacement. **Figure 2** illustrates a dynamic measurement of a transducer's suspension stiffness, $K_{ms}(x)$ from the Klippel ana-

FIGURE 1: Plot of reaction force vs. displacement from a low-frequency spider measurement.

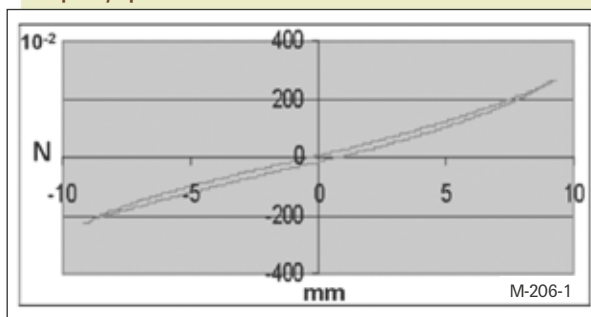
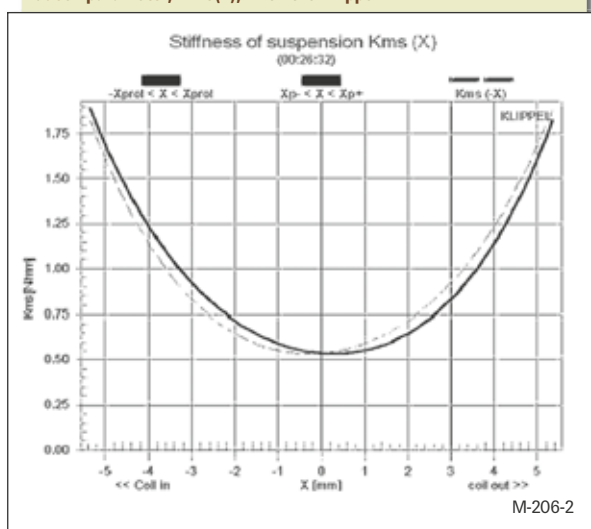


FIGURE 2: Dynamic measurement of the large signal transducer parameter, $K_{ms}(x)$, with the Klippel.



lyzer/measurement system. The transducer in this measurement had a treated cloth spider. This illustrates problem number four; nonlinearity and/or asymmetry in the stiffness of the spider. The spider stiffness/compliance changes with voice coil position. It is this parameter, $K_{ms}(x)$, along with the motor force factor linearity, that controls and determines the maximum linear displacement capability of the moving assembly, X_{max} , such that $1.33K_{ms}(0) = K_{ms}(X_{max})$.

If things weren't bad enough, there is problem number five: creep. Note the first natural frequency of the transducer, f_0 , where

$$f_0(x) = \frac{1}{2\pi} \sqrt{\frac{K_{ms}(x)}{M_{ms}}} \text{ (Hz)}$$

but displacement changes with frequency and current, $X(f,I)$.

What's the answer? It could be injection-molded TEEE spiders, Thermo Ether/Ester Elastomer. Spiders and surrounds made from this material could result in improvements in all problem categories identified, including significant reductions in inherent variability, reduction in hysteresis, improved material property stability, and resistance to creep and fatigue. TEEE is used extensively in the automotive industry for air bags and CVJ boots. TEEE also has medical equipment applications.

SPIDER SIMULATIONS

I will use proprietary nonlinear single degree of freedom finite element analysis to evaluate what to expect from TEEE spiders relative to a heavy cotton/nomex cloth blend spider.

The material properties used were as follows.

Treated Cloth (Cotton/Polyester)

Modulus of elasticity = 25,000 PSI, Poisson's ratio = 0.3,
0.5mm thick

TEEE

Modulus of elasticity = 7,250 PSI, Poisson's ratio = 0.3,
0.5mm thick

Santoprene (TPE)

Modulus of elasticity = 290 PSI, Poisson's ratio = 0.3,
2.0mm thick

TEEE is available in several moduli of elasticity, but treated cloth has high modulus, in tension. The material properties of both cloth and TEEE are for example only, and material properties should always be obtained directly from the material supplier. However, cloth has a significantly higher modulus of elasticity than TEEE and all other thermoplastic elastomers (TPE) and rubbers.

Figures 3 and 4 illustrate the static and displaced geometry of the spider analysis example. The force is incrementally evaluated as the axisymmetric geometry is displaced in the positive and negative axial directions, respectively.

The TEEE spider is more compliant than the heavy cloth spider (**Figs. 5 and 6**). The total stiffness of the transducer, $K_{ms}(x) = K_m(x) + K_s(x)$, the stiffness of the surround plus the stiffness of the spider. Ideally, $K_{ms}(x) = 2K_m(x) = 2K_s(x)$, the stiffness of the spider and the surround are equal. A different grade of TEEE may be required for the surround versus the spider to implement this.

What about the TPE, Santoprene? I don't think so; however, I did not fully investigate the geometric stiffness, even

FIGURE 3: Static and positive displaced axisymmetric spider shape.

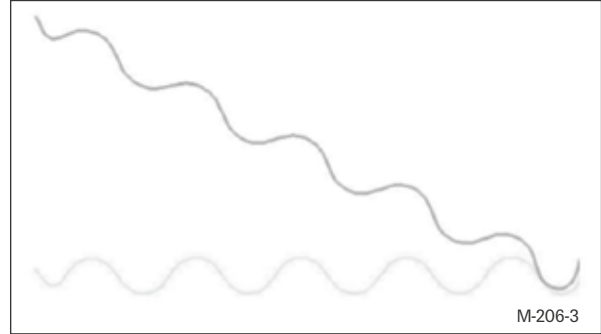


FIGURE 4: Static and negative displaced axisymmetric spider shape.



FIGURE 5: Simulation of reaction force vs. displacement.

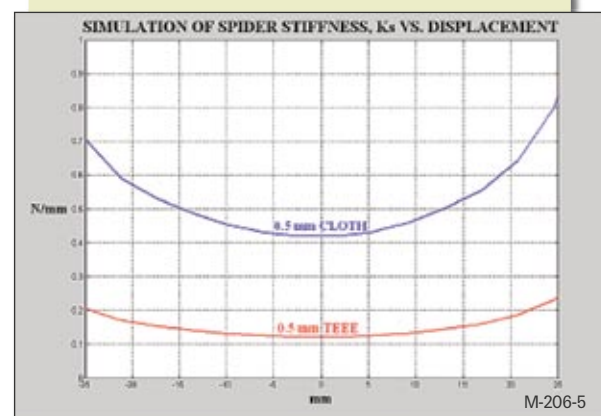


FIGURE 6: Simulation of spider stiffness vs. displacement.



though Santoprene's modulus of elasticity, $E = 290$ PSI! That's very low. A Santoprene spider would need to be much thicker and much heavier than a cloth or a TEEE spider. Although every case of geometry and material is different, it looks as though Santoprene is just too soft for spider application.

It seems that the spider's stiffness goes as the tensile modulus of the material, and the linearity goes inversely with the material thickness. However, there are infinite combinations of geometry and materials. I'll take the TEEE. It also handles much higher temperatures, 135°C maximum for Santoprene versus 165°C maximum for TEEE, which is 30°C !

Simulations of a 2.0mm thick Santoprene spider are illustrated in **Figs. 7 and 8**. The spider model indicates that linearity is reduced and, at 2.0mm thick, the moving mass is increased but the simulated compliance is still too high. The Santoprene spider should be even thicker; however, linearity would be further reduced.

These simulation results are consistent with several years of research into transducer suspension part design and indicate to me that spider linearity and symmetry is dominated by spider geometry, while stiffness, variability, and damping are dominated by material selection.

ADDITIONAL SPIDER PROBLEM

The sixth and most universal problem with the spiders cannot be solved with material and/or process selection. The spider vibrates at the same frequency as the cone. Typically, the spider is mounted quite close to the cone on the same voice-

coil bobbin, neck joint(s). Thus the spider radiates sound pressure that travels through the cone and modulates with the sound pressure radiated from the cone; however, the cone is designed to be stiff while the spider is designed to be flexible. The spider is a poor diaphragm. Why would anyone place the spider behind the cone?

The typical transducer actually has two diaphragms, the cone and the spider. **Figure 8** illustrates the typical suspension/moving assembly configuration. **Figure 9** shows an example of a transducer concept with topology that isolates

FIGURE 9: Typical low-frequency transducer topology.

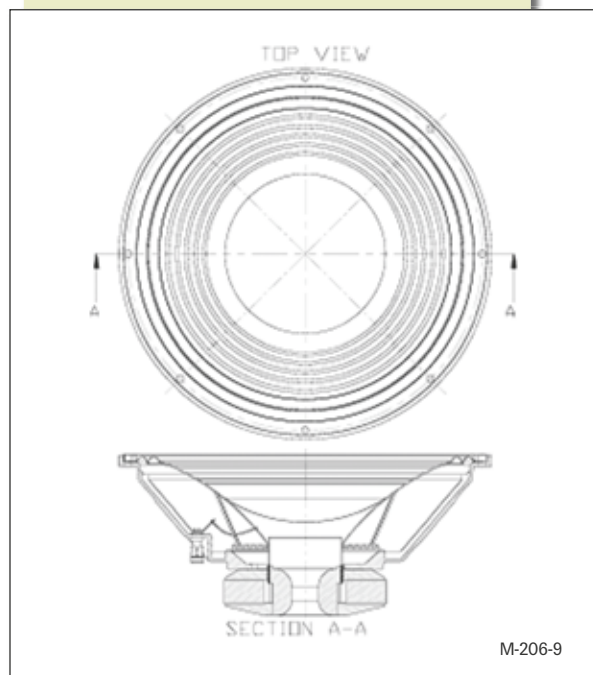


FIGURE 7: Simulation of reaction force vs. displacement.

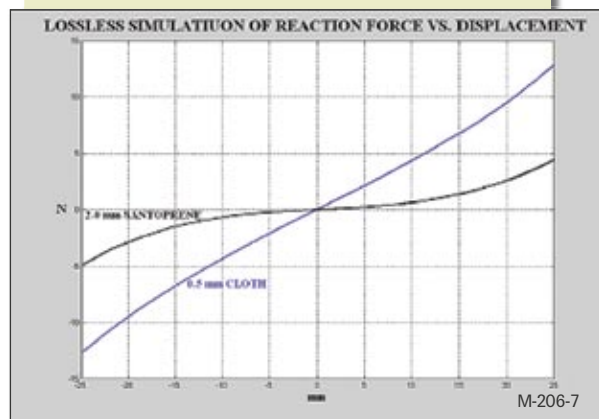


FIGURE 8: Simulation of spider stiffness vs. displacement.

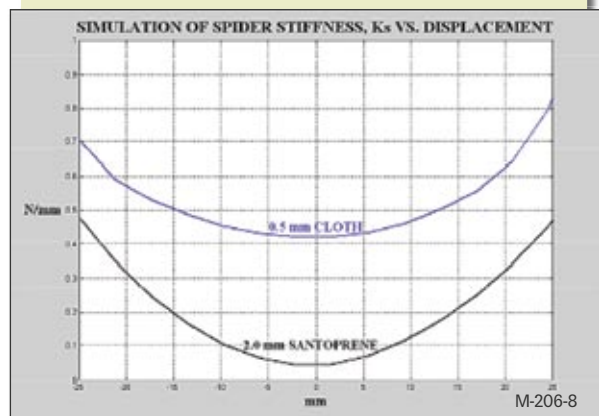
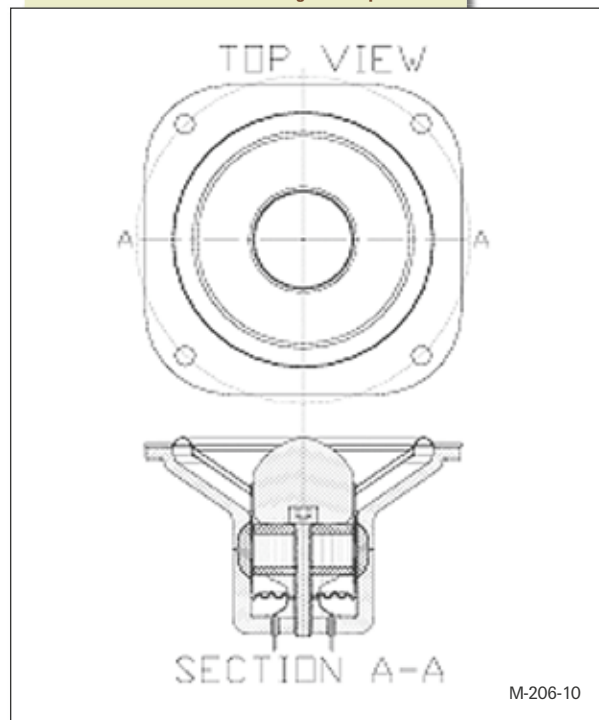


FIGURE 10: SM Audio midrange concept.



the spider radiation from the primary diaphragm, the cone. This problem can be designed-out with a non-cantilevered moving assembly and a center of mass that is almost ideally located between the surround and spider along with push-pull drive.

CONCLUSION

TEEE materials seem to offer an opportunity to improve transducer linearity, while the rear-mounted spider should reduce coloration and improve mechanical stability. Suspension components, spider and surround, manufactured with TEEE materials, will add robustness to transducers. Two major failure modes for transducers are suspension and lead-out noises. The TEEE injection-molded spider is an ideal application for integral tinsel-molded 180° annular radial to the ID and OD. Also, the injection-mold process is capable of much more consistent parts (spiders) than the cloth over die with heat method. Furthermore, the injection-mold process is not new to component suppliers, and TEEE is a mold-friendly material.

Finally, there is a material for suspension components with consistent homogeneous material properties that you can adjust in the material formulation and not by adding or changing treatment and/or process temperature. Any reasonable thickness, including non-constant thicknesses, can be molded. Cloth is available in only three or four thicknesses, and the resultant cloth thickness is also the result of the process.

Having had the opportunity to visit facilities that manufacture treated cloth spiders, I can appreciate the elegance of the simplicity of the injection-mold process relative to the multi-step cloth spider manufacturing process. Specifically, the cloth must first be treated. Is the cloth itself consistent? Is the treatment consistent? The treated cloth is then formed between two heated dies.

Subsequently, the spider's ID and OD are cut with cutting dies. Are these processes consistent? Why is the spider and/or surround cloth? This is cost driven and/or rhetoric driven and not performance/quality driven.

The TEEE parts are simply molded from material that is supplied in pellets. On a highly automated assembly line, suspension parts along with other transducer components could be made in real time during the transducer manufacturing process. No spiders and surrounds to inventory. However, what is really needed is to design, develop, and manufacture TEEE suspension parts within Asia. **VC**