24th INTERNATIONAL CONGRESS ON SOUND AND VIBRATION
23–27 July 2017, London

RESEARCH ON THE EQUILIBRIUM PERFORMANCE OF FRAMEWORK LAYER OF PNEUMATIC VIBRATION ISOLATOR

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This document is on the base of structure simplification of the RSA's cord, geometric analysis and force-equilibrium equations of microelements that are used to get the theoretic equilibrium-wound angle of the RSA's cord, then present the concept of equivalent equilibrium-wound angle. The research results provide theoretic basis for the selecting of parameters and simplification of technologies in the RSA's design and manufacture.
Keywords: reversible sleeve air spring, cord, equilibrium-wound angle, equivalent equilibrium- wound angle

Air spring, also known as air sac vibration isolator, is widely used as a component of vibration and noise reduction. According to the sac body structure, the air spring can be divided into gasbag type, reversible sleeve type and mixed type. The reversible sleeve air spring(RSA) is characterized by effective area changing rate and low natural frequency, and when the isolator's natural frequency is not higher than 2.5Hz, the general choice is the RSA [1-4].

When the sac body of the RSA is formed, the cord ply needs to be made in advance. The existing technology is not studied deeply on the cord's wound angle. However, in the process of using the RSA, the bending moment, torque and internal stress of the membrane wall can be generated in the rubber bag body, which can cause the deformation of the capsule body and affect the normal work of the system, or even cause serious consequences. So in the production of RSA, the reasonable laying of cord angle is vitally important, which to meet the mechanical balance requirements, to ensure the air sac vibration's performance and bearing capacity and to reduce the deformation of the capsule body. Therefore, it is very necessary to do research on the cord's wound angle in reversible sleeve air spring [5-7]. Through geometric analysis and stress calculation, the expression of cord's wound angle and mechanical equilibrium angle is calculated, and then determine the equilibrium-wound angle, and put forward the concept of equivalent equilibrium-wound angle. Meanwhile, the correctness of the calculation results and the existence of the equivalent equilibrium-wound angle are demonstrated by the finite element simulation analysis.

1. Brief introduction and modelling

1.1 Brief introduction of the research object

In this paper, the research object is a typical membrane air sac, which is shown in Figure 1.The air bag is mainly composed of an airbag body, a cover plate and a protective flange and the air chamber of the air bag is sealed by the rubber bag body and the metal structure, which is mainly constituted of the inner layer, the cord layer and the outer layer. The cord layer is the main bearing part, which is wrapped in the inner and outer glue layers and divided into multiple layers, and each layer is coated with a certain angle, showing the characteristics of anisotropy.

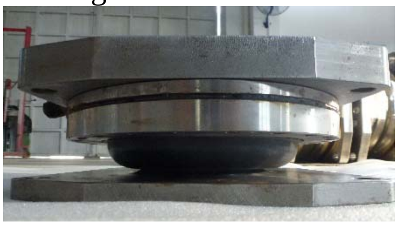

Figure 1: The simple of ELF-RSA

1.2 Geometric modelling of semi-circular ring shell structure

The size and structure of cord line layer's thickness relatively to the airbag body is very small. Meanwhile, the structure, load and boundary conditions of the capsule body are symmetrical, which meet the assumption of the shell and the non-moment theory about elastic mechanics, so it can be capsule for rotating thin shell processing.

The airbag body model is shown in Figure 2, the first and the third part respectively for the cylindrical shell, which is mainly bearing tensile stress; the second part is the half circle around the centre line of rotation a week member semi-circular shell, which is bearing complex stress conditions. In this paper, the wound angle of the cord in the second parts is analysed. Take second parts to establish the coordinate system, as shown in figure 3.The radius of cross section is r, and the distance between the centre of the cross section and the axis of Z is R (the basic size of the object studied in this paper is: R=70mm, r=19mm). φ is expressed of r along the semi-circular shell centre line turning angle, and θ is characterized by R along the Z axis through the angle. Then the coordinates of any point on the semi-circular shells can be uniquely represented by (θ,φ).

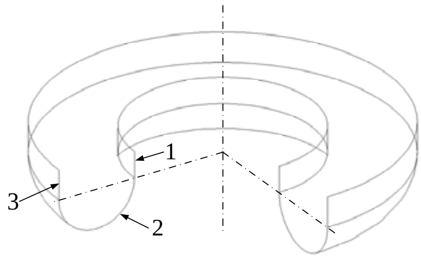

Figure2: Lamina model of ELF-RSA

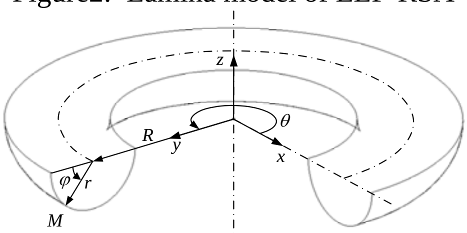

Figure 3: Coordinate system of part 2

Therefore, the parameters of θ,φ are used as the variable, the parameters of i_θ and i_φ are used as the unit tangent vector along parameter curve, and the parameters of α is defined as the wound angle from the unit tangent vector i_φ steering cord wound path, as shown in figure 4:

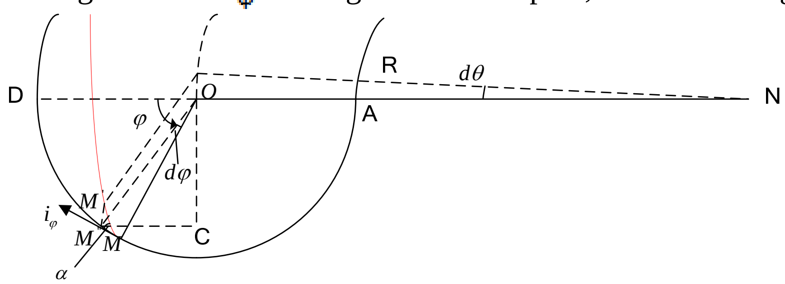

Figure 4: Figure for geometrical analysis

The semi-circle shell is uniform in the pipe diameter, and the cord's wound on the shell surface can be considered as a part of the space spiral along the curved surface of the shell, which is shown in the red line in figure 4. From the geometric relation in the graph, the wound track equation of the cord of the semi-circle shell is:

$$\left.\begin{aligned} x &= (R + r\cos\varphi)\cos\theta \\ y &= (R + r\cos\varphi)\sin\theta \\ z &= -r\sin\varphi \end{aligned}\right\} \tag{1}$$

In the formulas：

$$\varphi = \varphi(\theta) \tag{2}$$

2. The equilibrium-wound angle of cord

2.1 The calculation of equilibrium-wound angle of cord

From the Figure 4, when the radius NO of the annual shell around the Z rotation turns $d\theta$ angle, the cord length is BB′ accordingly; similarly, when the radius OB of semi-circular turns $d\varphi$ angle, the cord length is BB″ corresponding in the arc section. By the geometric relationship, the cord wound angle is equal in value to the angle B′BB″, as shown in figure 5:

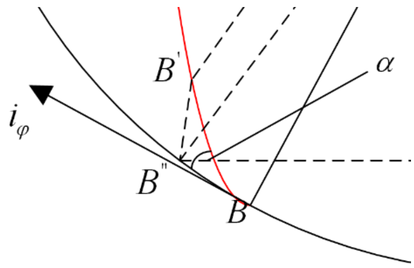

Figure 5: Figure for wound angle calculating

The analysis combined with the figure 4 shows:

$$B^{'}B^{''} = (R + r\cos\varphi)d\theta\,; \quad B^{''}B = rd\varphi$$

The tangent expression of the cord’s wound angle is obtained:

$$\tan\alpha = \tan\angle B^{''}BB^{'} = \left|\frac{(R + r\cos\varphi)}{r}\frac{d\theta}{d\varphi}\right| \tag{3}$$

In addition, get $d\theta$、$d\varphi$ as the unit micro element in the arbitrary B element in the semi-circular shell of the airbag body , which is received the elastic force P_1、P_2 in the direction of $\mathbf{i}_\theta$ and $\mathbf{i}_\varphi$. The expression of hoop stress ${}_p\sigma_m$ and axial stress ${}_p\sigma_n$ respectively are:

$$P_1 = {}_p\sigma_m \cdot (R + r\cos\varphi)\cdot d\theta \cdot t\,; \quad P_2 = {}_p\sigma_n \cdot r \cdot d\varphi \cdot t \tag{4}$$

$${}_p\sigma_m = \frac{PR}{2t}\cdot\frac{2R + r\cos\varphi}{R + r\cos\varphi}\,; \quad {}_p\sigma_n = \frac{PR}{2t} \tag{5}$$

Inside, the parameter of t is the airbag wall’s thickness. So the angle of the stress resultant force at the point is:

$$\tan\bar{\alpha} = \frac{P_2}{P_1} = \frac{{}_p\sigma_n}{{}_p\sigma_m}\cdot\frac{rd\varphi}{(R + r\cos\varphi)d\theta} \tag{6}$$

Because of the cord not bearing the shearing force, the equilibrium direction of the cord at point B coincides with the stress direction at the point, and that is, the angle $\bar{\alpha}$ is the angle of mechanical equilibrium.

When the airbag body is inflated, its balance can be maintained only when the stress direction of the cord is consistent with the winding direction. Therefore, the wound angle is characterized as the air spring's equilibrium-wound angle, when the initial cord's wound angle α at the point B is equal to the mechanical equilibrium angle $\bar{\alpha}$, that is, the internal force just falls on the curtain cord line at this time.

$$\bar{\alpha} = \alpha \tag{7}$$

Then, the simultaneous (3), (5), (6), can be used to obtain the expression of the wound angle of the air spring's body in the semi-circle shell:

$$\tan\alpha = \sqrt{\frac{R + r\cos\varphi}{2R + r\cos\varphi}} \tag{8}$$

In this study, the range of the angle is 0 to π, the corresponding relationship between θ and φ can be obtained, as well as the cord in the capsule body' wound track in theory, as shown in figure 6:

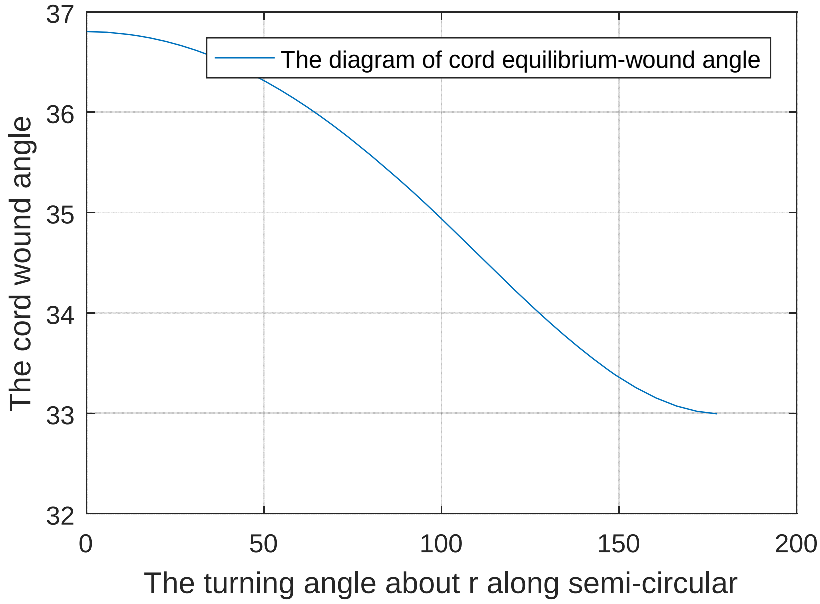

Figure 6:The cord's equilibrium-wound angle

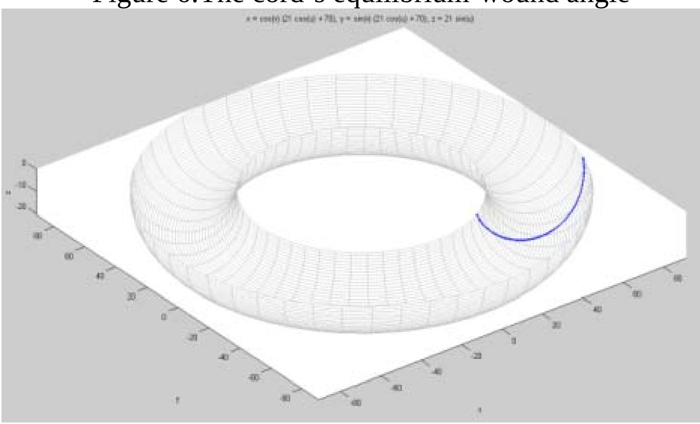

Figure 7 Path of the cord wounding by equilibrium-wound angle

2.2 Equivalent equilibrium-wound angle

The effective time and performance of the air spring are influenced by the balance of the bag body of the air spring. In the manufacture of reversible sleeve type air spring, if the cord in accordance with the above equilibrium-wound angle is laid on the airbag body, when the air spring is received the inner pressure, the cord is just under the stress of the capsule body; if the cord deformation is ignored, the angle between cords will not change and the airbag body cannot deform, so then the air spring can get the best balanced addition. However, in the actual production process, due to the limitations of production technology and cost reasons, the cord is difficult to track the line in the trajectory of the laying, according to figure 7.

By the process of calculating equilibrium-wound angle, when the bag body is inflated, the wound angle α can be reduced due to the airbag body stretched, and the cord force regain balanced, when the cord's wound angle is greater than the mechanical balance angle. Vice versa. Therefore, a suitable equivalent equilibrium-wound angle can be selected from the range calculation results of the cord's equilibrium-wound angle in the project, and make the cords in the annular airbag body laid according to this angle and make the tensile deformation and shrinkage deformation of the airbag body offset, which is to ensure that the airbag body is in the best balance at this wound angle when it is inflated. In other word, when the airbag body's deformation reaches minimum and uniform, the aims about reducing the costs and simplifying the process without loss of property get achieved.

3. Finite element simulation analysis

3.1 Finite element simulation and results

The rebar element of MSC.MARC finite element simulation software can be used to simulate the structure of the cord reinforcement layer. The rubber material is defined by the Mooney materials: C10=-1.91MPa，C01=3.546MPa，C11=0.338MPa. The cord is defined by the aramid material: E=33.882GPa.The 82herrman unit is used to simulate the capsule rubber, and the cord is simulated by 144rebar element. The inflation pressure is 2.0MPa, and adopt the axisymmetric analysis of the model. The wound angle of the cord is simulated and analysed respectively 36 degrees, 35 degrees and 34 degrees according to the theoretical wound angle, and the 30 and 40 degrees are selected for comparison, so the results of the airbag body's deformation are shown in the figure.

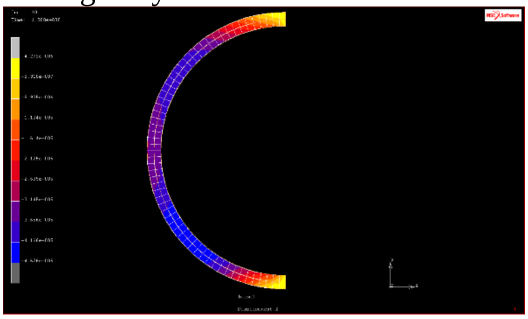

Figure 8: Equilibrium-wound angle in cord theory

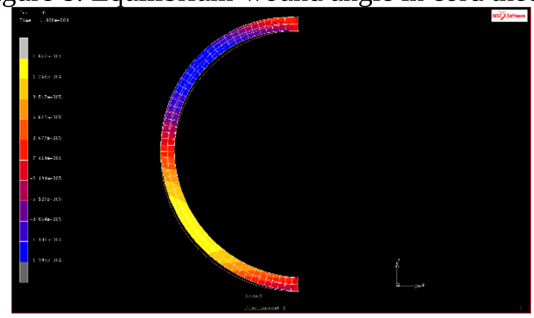

Figure 9: Cord winding angle: 30 degree

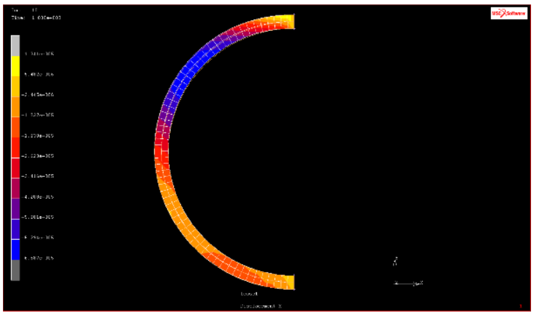

Figure 10: Cord winding angle: 34 degree

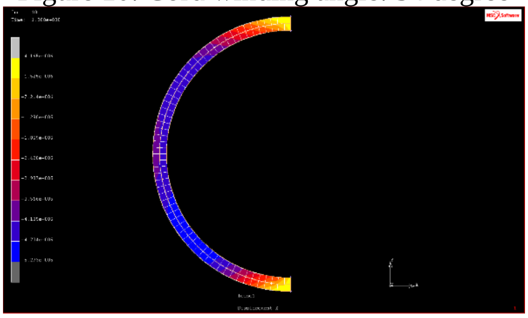

Figure 11: Cord winding angle: 35-degree

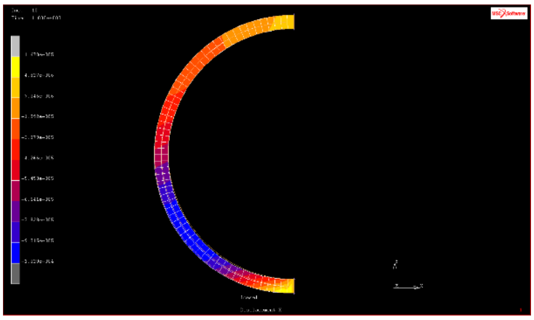

Figure 12: Cord winding angle: 36 degree

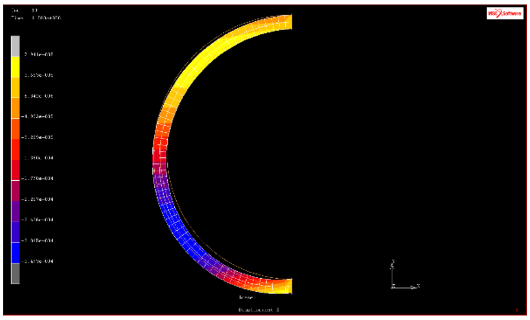

Figure 13: Cord winding angle: 40 degree

Table 1 : the range of the airbag's axial displacement(mm)

Axial displace-ment	Theoretical degree	30 degree	34 degree	35 degree	36 degree	40 degree
Max	0.004	0.154	0.013	0.004	0.017	0.079
Min	-0.047	-0.139	-0.066	-0.052	-0.102	-0.349

3.2 The analysis of simulation results

Comparison of the results of the 6 simulation can be seen:

When the cord winds according to the calculation of the equilibrium-wound angle, the air spring's deformation is the smallest, while it is deformed in the range of -0.047 to 0.004mm after inflating. In addition, the deformation of the inner and outer airbag wall is uniform in this condition as shown Figure 9, and the airbag body is in the best balance, which demonstrates the results of theoretical calculation in this paper.

When the cord is wound at a fixed angle, in 35 degrees, the air spring's deformation is the smallest, while it is deformed in the range of -0.052 to 0.004mm, and its deformation of the inner and outer airbag wall is uniform and the airbag body is basically equivalent according wingding as the equilibrium-wound angle, which demonstrates the existence of the equivalent equilibrium-wound angle.

When the cord wound angle is greater than 35 degrees, the inner side of the airbag body presents an expansion deformation, and the outer is contraction deformation; When the cord wound angle is less than 35 degrees, the inner part of the airbag is in the form of the contraction deformation and the outer is the expansion deformation. The deformation trend of the capsule is consistent with the former. Moreover, the more the wound angle deviates from the 35 degree, the larger the deformation of the airbag body is, the more uneven the deformation is.

4. Conclusion

Based on the analysis of the part of semi-circle shell of a reversible sleeve type of air spring, the theory of the equilibrium-wound angle is studied, the relevant formulas are proposed and the validity is verified by simulation experiment.

（1） The formula for calculating the equilibrium-wound angle of the air spring's cord is deduced. When the cord is wound on the basis of the equilibrium-wound angle, the air spring is balanced;

（2） The concept of the equivalent equilibrium-wound angle is put forward. According to the angle of winding the cord, the production process is simplified under the premise of ensuring the excellent balance of the air spring body under the action of internal pressure.

The results of this paper can provide a theoretical basis for the selection of parameters in the design and construction of the air spring, and provide theoretical guidance for the improvement of the production process of the cord layer in the process of the air spring.

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