Journal of Southeast University (English Edition) Vol. 22, No. 4, pp. 505 – 509 Dec. 2006 ISSN 1003—7985

Experimental research on static characteristics of special wire-rope isolator

Jiang Hongyuan[1] Yan Hui[1] Li Guixian[1] Alexander M. Ulannov[2]

([1]Department of Machine Design, Harbin Institute of Technology, Harbin 150001, China)

([2]Department of Structure and Design of Aircraft Engine, Samara State-Maintained Aerospace University, Samara 443086, Russia)

Abstract: Based on analysis of the work conditions and structural characteristics of the exterior pipeline of the aero-engine, a kind of cantilever-structure wire-rope isolator fitted to the exterior pipeline of the aero-engine is designed for supporting and damping purposes. By static experiments, the static hysteresis loop, the relationship of stiffness and amplitude, and the relationship between the energy dissipation coefficient and the amplitude are obtained. Analyses show that the wire-rope isolator presents obvious hysteresis characteristics, and the characteristics of the isolator, such as stiffness and damping, behave obviously nonlinearly when the amplitude value of deformation changes. At the same time, by changing the structure parameters of the wire-rope, the wire-rope isolators can be made with different functions to satisfy different work conditions. The research results have important reference values for the application of the wire-rope isolator on the exterior pipeline of an aero-engine.

Key words: wire-rope isolator; pipe-support; hysteresis characteristic

Dry friction damping elements can be well employed to effectively repress structural vibration through an energy-consuming mechanism. For several decades, many scholars have done thorough research in this sector[1−2] and the research achievements have laid a solid foundation for further theoretical studies and engineering applications of new dry friction damping isolators[3−5], such as the wire-rope isolator, the metal rubber isolator, the multi-layer steel-plate isolator and the wire-net isolator, etc.

The wire-rope isolator is a wholly metallic dry friction damping isolator, a kind of nonlinear isolator with hysteresis characteristics and many advantages such as intenerated stiffness, large damping ability, good resistance against heat, corrosion and aging, stable functionality, good maintenance and manufacturability as well as low cost; thus, it is particularly suitable for use in hostile environments[6]. Though wire-rope isolators have already been applied in the realms of aviation and aerospace, machinery, ships and transportation etc., many kinds of products available in the market cannot be directly used for exterior pipe-support of aero-engines because of the space limitations for exterior pipe-support of aero engines and the requirements of a passive damping isolator to reduce vibrations delivered from the engine to the pipe through a card hoop[7]. In this paper we design a passive wire-rope isolator for pipe-support in consideration of the concrete characteristics of the exterior engine pipe and investigate its static characteristics.

1 Design of Wire-Rope Isolator for Pipe-Support

Wire rope in the isolator plays a great role for the isolator to fulfill its function. The material, the structure parameter and the diameter of wire rope all affect the functions of the wire-rope isolator, so the selection of the wire-rope is very important.

1.1 Selection of wire-rope material and structure parameters

Wire-rope on the market currently is standardized, the diameter of wire-rope ranging from a few millimeters to several centimeters. There are many kinds of wire-ropes according to the structure parameters, such as 1×7, 1×1, 6×7 + IWS, 6×7 + NF, 6×19 + IWS, 6×19 + NF etc[5].

From preliminary experiments we find that the structure parameters of wire-rope has a great influence on the performance of the wire-rope isolator. This is because while the wire-rope isolator is working, the dry friction produced between steel wires in the rope performs a damping role. So when making the wire-rope isolator, we need to investigate the influence of

Received 2006-02-23.

Foundation item: The National Natural Science Foundation of China (No. 50275030).

Biography: Jiang Hongyuan (1960—), male, doctor, professor, jhy _ hit @ sina. cm.

the structure parameters upon its function. The research indicates that it functions well if the number of wires in the rope is between 40 and 200, but rope with a large number of wires means it has a large diameter. Generally, if the number of wire-rope exceeds 6×19, its diameter is bigger than 3 mm. Considering the work conditions of the exterior pipe of engine diameter and the pipe system comprehensively, we decide that the wire-rope diameter should be limited to 3 mm, and choose ropes with three kinds of structural parameters for isolators, namely, 1×7, 6×7 + IWS, 1×19.

According to the cases used, wire-ropes can be divided into normal wire-rope, aviation wire-rope, special wire-rope of car, manipulation wire-rope, zinc-coated wire-rope, etc. In this text, the aviation wire-ropes made of stainless steel are used.

1.2 Design of wire-rope isolator

Considering the work conditions of the exterior pipe of the engine system, we designed the wire-rope isolator with a structure similar to a cantilever, as shown in Fig. 1. We can see that the wire-rope isolator is composed of the wire-rope, pressing plank and yoke.

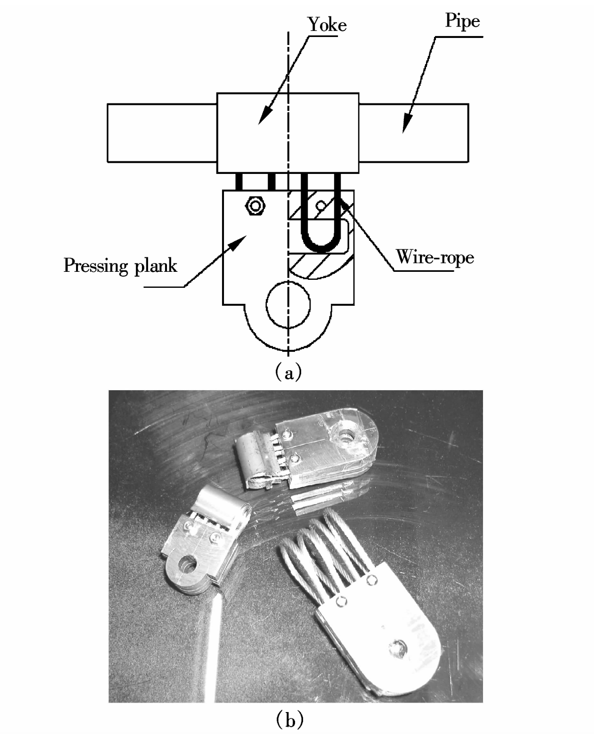


Fig. 1 Structure and photo of wire-rope isolator. (a) Structure; (b) Real objects

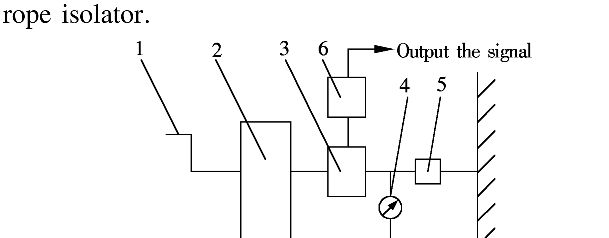
We install it onto the pipe with a stud bolt, then fix it tightly on the base by a bolt. To prevent the isolator moving during work, the yoke is used to fix the touching part with the pipe. On the premise of satisfying the strength requirement, we use steel 45 to make the pressing plank of the wire-rope isolator. The wire-rope isolator weighs 43 g when the wire-rope of the structure parameter 1×7 is used, and it weighs 65 g when the structure parameter is 6×7. Fig. 1(b) shows a few real wire-rope isolator objects with different structure parameters.

2 Static Characteristics Tests

Static tests are mainly loading and un-loading tests on a static experiment device for wire-rope isolators with different structure parameters, thus obtaining the curves of deformation to the related load, i. e., the static hysteresis curves. By analyzing these curves, we can obtain the stiffness-deformation relationship and the energy consumed-deformation relationship of the isolator, from which we can further draw its static characteristics, i. e., stiffness characteristics and damping characteristics.

2.1 Test rig and its principle

The test rig is shown in Fig. 2. The wire-rope isolator system is fixed on the experiment stage with a stud bolt. The isolator is connected to force-applying device through the force-transducer. The load can be applied to the wire-rope isolator by turning the handle, and the value of the force is converted to electric voltage through a signal-converting device. Thus we can reconvert the read electric voltage value to the applied force on the isolator by calibrating the conversion factor of voltage to force (here, 0.4 mV/kg). The head of the deformation meter touches the blocking plank to measure the deformation of the wire-rope isolator.



1—Handle; 2—Force-applying device; 3—Force-transducer; 4—Deformation meter; 5—Wire-rope isolator; 6—Signal converting device

Fig. 2 Scheme of static experiment system

2.2 Static characteristic of wire-rope isolator

Two static characteristics of the wire-rope isolator are studied in the research, i. e., stiffness and damping characteristics. The dry friction damping characteristic can be represented by energy dissipation ratio ψ.

The stiffness and damping characteristics of the wire-rope isolator can be calculated by a static hysteresis loop. Fig. 3 shows a simple hysteresis loop, in which the dotted line represents the centerline of the hysteresis loop, drawn by the averaging values of the loading curve and the unloading curve. Because the hysteresis loop of the wire-rope isolator under large deformation is almost linear, so the centerline of the hysteresis loop can be treated approximately as a straight line. Usually, the average stiffness is signified by the slope of the centerline, but considering the big error in average stiffness near the two sides of the deformation, we treat the average stiffness as the slope of the centerline at 70% maximum deformation.

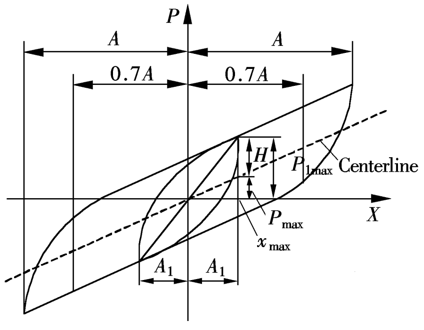


Fig. 3 Predigest hysteresis loop of wire-rope isolator

In this paper we make use of the static hysteresis loop to calculate the actual stiffness of the wire-rope isolator at a certain deformation value. We can approximately calculate the average stiffness and the actual stiffness of the wire-rope isolator from the above analysis.

$$k_s = \frac{P_{max}}{x_{max}} \quad (1)$$

$$k_d = \frac{P_{1max}}{A_1} = \frac{H + P_{max}}{A_1} = k_s + \frac{H}{A_1} \quad (2)$$

where k_s is the average stiffness of the wire-rope isolator(N/mm); k_d is the actual stiffness of the wire-rope isolator (N/mm); x_{max} is the biggest deformation value (mm); P_{1max} is the biggest reacting force(N); A_1 is the deformation amplitude value in the hysteresis loop (mm); H is the average interior friction (N).

Fig. 4 is the ideal hysteresis loop, the energy dissipation parameter ψ of the wire-rope isolator can be signified with following formula:

$$\psi = \frac{\Delta W}{W} \approx \frac{2\pi T}{P_{max}} \quad (3)$$

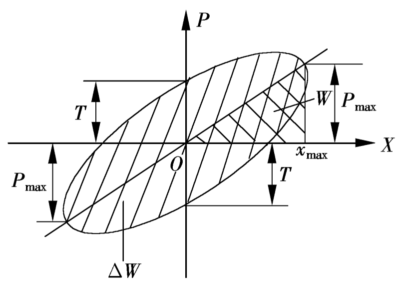


Fig. 4 Ideal hysteresis loop

$$\Delta W \approx \pi x_{max} T \quad (4)$$

$$W = \frac{1}{2} k_s x_{max}^2 \quad (5)$$

where ΔW is the energy dissipation capacity in a cycle (N·mm); W is the greatest deformation potential energy(N·mm); T is the reacting force at the zero point of deformation(N).

3 Static Characteristics Analysis of Wire-rope Isolators of Different Structure Parameters

To get static characteristics of wire-rope isolators of different parameters, we carry on static experiments for wire-rope isolators with structure parameters of 1 ×7 ×0. 32 mm, 1 × 19 × 0. 3 mm and 6 × 7 × 0. 2 mm, respectively. Analysis is made by the hysteresis loop of wire-rope isolators with different structure parameters, stiffness-deformation and energy dissipation-deformation relationships which are based on the experiment data.

3.1 Hysteresis characteristics analysis of wire-rope isolators with different structure parameters

Fig. 5 shows hysteresis loop of the wire-rope isolator under different deformation amplitude values for structure parameter 6 ×7 ×0. 2 mm. We can see from this figure that the wire-rope isolator has obvious hysteresis characteristics when the deformation reaches a certain value. The bigger the area which the hysteresis loop surrounds, the more vibration energy it can absorb. This is because, the wire-rope isolator is made from many stainless steel wires. When the deformation is smaller, less friction occurs between the wires. When the deformation becomes large enough, great friction occurs between the wires. So the load-deformation curve of the experiment shows that the wire-rope isolator has hysteresis characteristics.

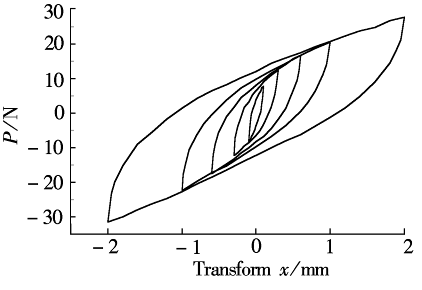


Fig. 5 Hysteresis loop of wire-rope isolator with parameter 6 ×7 ×0. 32 mm

Fig. 6 shows hysteresis loops of wire-rope isolators with different parameters at the structure parameter of wire-rope. The hysteresis loop of structure parameter 1 × 19 × 0. 3 mm has the greatest area surrounded, parameter 6 × 7 × 0. 2 mm has the second, the smallest is that of parameter 1 × 7 × 0. 32 mm. It indicates that the energy consumption property is different for wire-rope isolators with different structural parameters, and so are its isolating and damping characteristics.

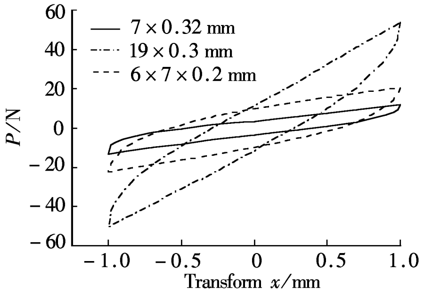


Fig. 6 Hysteresis loops of wire-rope isolators with different parameters

3. 2 Stiffness characteristics analysis of wire-rope isolators with different structure parameters

For wire-rope isolators with different structure parameters, the slopes of the centerline of their hysteresis loops are different, which shows that the average stiffness of isolator k_s will change with structure parameters. The experimental results indicate that the average stiffness of the wire-rope isolator with structure parameter 1 × 19 × 0. 3 mm is the largest, that of 6 × 7 × 0. 2 mm is the second largest, the smallest is that of 1 × 7 × 0. 32 mm (as shown in Fig. 7). On the other hand, for the wire-rope isolator, the centerline of the hysteresis loop is almost linear, which means that the average stiffness k_s and interior friction H are constant and actual stiffness can be approximately written as Eq. (2). As the deformation value increases, the actual stiffness of the three kinds of the wire-rope isolators all decrease, which indicates that the stiffness of the wire-rope isolator has "soft" characteristics, and the actual stiffness of the wire-rope isolator changes in deformation value by obvious non-linear characteristics.

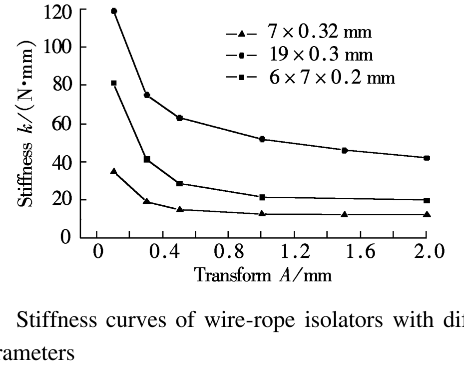


Fig. 7 Stiffness curves of wire-rope isolators with different parameters

3. 3 Damping characteristics analysis of wire-rope isolators with different structure parameters

For the dry friction damping isolator such as the wire-rope isolator, the energy dissipation capacity parameter $\psi = \Delta W/W$ is often used to indicate friction damping characteristics of isolators. As shown in Fig. 6, the area which the hysteresis loop of the wire-rope isolator surrounds changes for different structure parameters, so does the greatest deformation potential energy. Fig. 8 shows the relationships of energy dissipation coefficient-deformation for isolators with structure parameters of 1 × 19 × 0. 3 mm, 6 × 7 × 0. 2 mm and 1 × 7 × 0. 32 mm, respectively. We can notice sharp non-linear characteristics from these curves. The energy dissipation coefficient increases very quickly with the deformation value at the beginning and after reaching the maximum at a certain deformation value, gradually decreases. The reason for these non-linear characteristics is mainly that the deformation value is associated with the friction behavior between rope wires; i. e., when the deformation is small, rope wires hardly interact against each other, so the energy dissipation coefficient is very small at a small deformation value; on the other hand, rope wires move against each other in great intensity, and the energy dissipation coefficient reaches its maximum; at even a larger deformation value, the rope wires will detach a little, the friction between them becomes smaller, and so does the dissipation coefficient of the wire-rope. We can draw from the figure that the dissipation parameter of the wire-rope isolator is very great, with the greatest value reaching 3 or 4. Even at a relatively large deformation value we can also get good damping performance. For example, we can keep the dissipation parameter above 2. 5 for an isolator of structure parameter 6 × 7 × 0. 2 mm. The most distinguishing characteristic of the wire-rope isolator is its good damping property by which it can absorb more vibration energy, fulfilling better its vibration-isolating function.

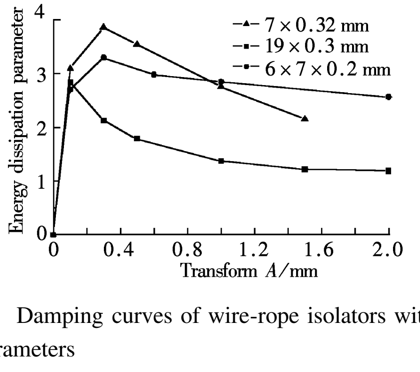


Fig. 8 Damping curves of wire-rope isolators with different parameters

4 Conclusion

The wire-rope isolator has good dry friction damping performance. The relationship between the stiffness and the energy dissipation coefficient is non-linear. The obvious soft spring characteristics of this kind of non-linear isolator is the reason why the wire-rope isolator has super loading ability and lower isolate frequency. The damping characteristic of the wire-rope isolator can be greatly affected by its structure parameters, such as the diameter of rope wire and wire numbers in a rope, etc. The experimental results show that we can design the wire-rope isolator with superior parameters under different working conditions.

References

[1] Den Hartog J P. Forced vibration with combined coulomb and viscous friction[J]. *Transactions of the American Society of Mechanical Engineers*, 1931, **53**(9): 107 − 115.

[2] Iwan W D. A distributed element model for hysteresis and its steady-state dynamic response[J]. *ASME Journal of Applied Mechanics*, 1966, **33**(4): 893 − 900.

[3] Tao Qihong. The foreign metal damping material and application[J]. *Voice and the Vibration Control*, 1987, **1**(3): 17 − 20.

[4] Bergan P G, Holand I, Soreide T H. Use of current stiffness parameter in solution of nonlinear problems[A]. In: Glowinski R, Rodin E Y, Zienkiewicz O C, eds. *Energy Methods in Finite Element Analysis*[C]. John Wiley & Sons, 1979. 265 − 282.

[5] Ao Hongrui. The dry friction damping mechanism and application studies of metal rubber [D]. Harbin: Department of Machine Design of Harbin Institute of Technology, 2003. 3 − 17. (in Chinese)

[6] Chen Weimin, Liu Gang, Chen Wei. Research on ring structure wire-rope isolators[J]. *Journal of Material Processing Technology*, 1997, **22**(5): 24 − 27.

[7] Barry L S. The importance of engine external health[A]. In: *The 7th International Symposium on Transport Phenomena and Dynamics of Rotating Machinery* [C]. Hawaii, USA, 1998, **45**: 572 − 580.

特种钢丝绳隔振器静态实验研究

姜洪源[1]　闫　辉[1]　李瑰贤[1]　Alexander M. Ulannov[2]

([1] 哈尔滨工业大学机械设计系,哈尔滨 150001)

([2] 萨玛拉国立航空航天大学飞行器发动机结构及设计系,俄罗斯萨玛拉 443086)

摘要:在分析航空发动机外部管路的工况和结构特点的基础上,设计了适合在发动机外部管路支承中使用的类似于悬臂梁结构的钢丝绳隔振器,并对其进行了静态实验研究. 静态实验中得到不同结构参数钢丝绳隔振器的滞迟回线、刚度−变形幅值关系曲线和能耗系数−变形幅值关系曲线. 通过分析表明:钢丝绳隔振器呈现明显的滞迟特性,隔振器的刚度、阻尼等性能随变形幅值变化表现出明显的非线性特性,同时,通过改变钢丝绳的结构参数,可以获得具有不同性能的钢丝绳隔振器,以满足不同工况的需求. 研究结果对钢丝绳隔振器在航空发动机外部管路中的应用具有重要参考价值.

关键词:钢丝绳隔振器; 管路支承; 迟滞特性

中图分类号:TB535