

Selection Methodology for Wedge Lock Strips in Avionics Equipment

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Abstract

This paper addresses the limitations of traditional wedge lock strip selection methods for Integrated Modular Avionics (IMA) equipment, which rely on subjective experience and lack systematic quantitative analysis. A systematic selection methodology integrating multi-dimensional engineering elements is proposed. This approach establishes a closed-loop decision process based on: Physical constraint identification, Material performance adaptation, Environmental load spectrum mapping, and Dynamic safety verification under vibration/shock conditions. By precisely balancing locking reliability and lightweight requirements, it resolves vibration-induced loosening failures and redundant weight issues. Validation on typical avionics equipment demonstrates that this method: Enhances vibration-resistant locking reliability; Optimizes structural weight; Meets stringent airworthiness requirements; Provides a universal selection framework for other modular electronic devices requiring anti-vibration fastening.

Keywords

Wedge Lock Strip; Avionics Equipment; Selection Methodology.

1. Introduction

The wedge lock strip serves as the core connecting component between the chassis and Line Replaceable Modules (LRMs) in Integrated Modular Avionics (IMA). Its structural characteristics enabling rapid locking and disassembly form the foundation for achieving quick maintenance and replacement within the entire IMA system. Against the backdrop of airborne electronic equipment evolving towards modularity, high density, and lightweight design, lock strips must simultaneously fulfill two core requirements: first, vibration-resistant locking reliability, ensuring structural stability of modules under extreme and complex operating conditions; second, lightweight adaptability, avoiding unnecessary weight gain in the overall equipment due to redundant lock strip design. The structural details and performance parameters of lock strips vary between manufacturers, making the selection of an appropriate wedge lock strip model critical during the structural design process of electronic equipment modules.

However, current engineering practice relies heavily on designers' empirical analogy for lock strip selection, lacking quantitative analysis of the locking force-vibration coupling mechanism. This deficiency readily leads to two typical issues:

Insufficient Locking Force: Locking failure under extreme vibration causing module detachment. For instance, during endurance testing of a certain radar module, the loosening failure rate reached 12%.

Excessive Locking Force: Over-selection of high-specification lock strips, resulting in increased equipment weight. For example, a certain Unmanned Aerial Vehicle (UAV) model experienced a 1.8kg weight increase, leading to an estimated 4.2-minute reduction in endurance [1].

The systematic wedge lock strip selection method proposed in this paper deeply integrates quantitative analysis at the design stage with precise implementation at the engineering stage, constructing a decision-making model covering the full lifecycle. Validated on an ARINC 600 compliant avionics device, this method achieved an increased safety margin under vibration conditions. It effectively mitigates the risks associated with experience-based selection, namely locking failure due to insufficient force or unnecessary weight gain due to over-specification. Consequently, the method offers valuable practical guidance for lock strip selection in similar modular electronic equipment.

2. Technical Fundamentals and Aviation Applications Analysis of Wedge Lock Strips

2.1 Structure and Operating Principle of Wedge Lock Strips

2.1.1 Physical Structure

The wedge lock strip consists of a slider, slide base, head screw, and auxiliary fixing components, such as spring plates and washers. Based on the number of slider segments, it can be classified into 3-segment type and 5-segment type, see Fig. 1[2].

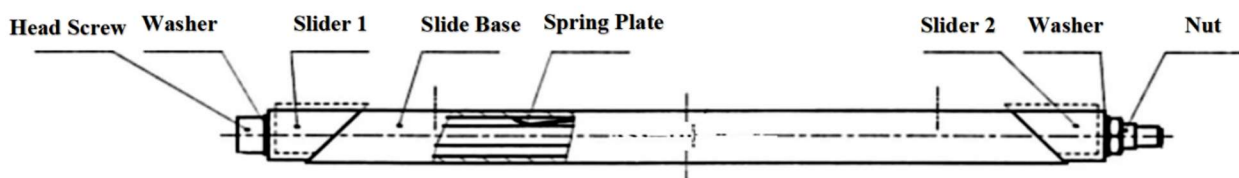


Fig. 1 Schematic Diagram of Wedge Lock Strip Structure

The slide base is fixed to the end of the equipment module being locked. The slider is the core transmission component engaging with the slide base. It is typically composed of multiple independent segments connected in series, featuring inclined surfaces with a specific wedge angle θ . The head locking screw converts rotational motion into axial movement of the slider via the thread pair.

2.1.2 Key Performance Parameters

The rationality of wedge lock strip selection directly determines the equipment's vibration resistance, reliability, and safety in harsh aviation environments. The critical basis for selection lies in a thorough understanding of its structure, operating principle, and core performance parameters.

The performance of the wedge lock strip can be characterized by the following key parameters:

Table 1. Core Performance Parameters of Wedge Lock Strips

Parameter Category	Parameter	Engineering Significance
Physical Dimensions	Length (L)	Determined by the length of clamped modules, considering installation space allowance
	Width (W)	Affects structural strength and space occupancy while adapting to mounting rail groove width
	Thickness (H)	Influences stiffness and load capacity; must minimize deformation under extreme conditions
	Wedge angle (θ)	Core geometric feature determining force amplification ratio and self-locking capability
	Number of segments (n)	More segments improve load distribution uniformity and adaptability to uneven surfaces
Mechanical Parameters	Material friction coefficient (μ)	Friction coefficient at slider-guide interface; directly affects locking force magnitude and anti-vibration slippage resistance
	Locking torque (T)	The input torque applied to the locking screw to generate the required clamping force : $F_a = \frac{T}{k \cdot d}$, k is Torque coefficient ; d is Nominal diameter of the tightening screw.

2.1.3 Working Principle and Force Analysis

The core operating principle of the wedge lock strip is based on the mechanics of the wedge slope: Rotating the locking screw drives the slider axially along the wedge-shaped guide rail via the thread pair. As the movable slider advances until it contacts the equipment slot, it generates a normal force against the inner sidewall of the slot. This normal force, in turn, produces friction forces at the contact interface. The sum of these friction forces constitutes the clamping force of the lock strip, thereby securing the clamped module. For force analysis (using a 5-segment wedge lock strip as an example), see Fig. 2 [3].

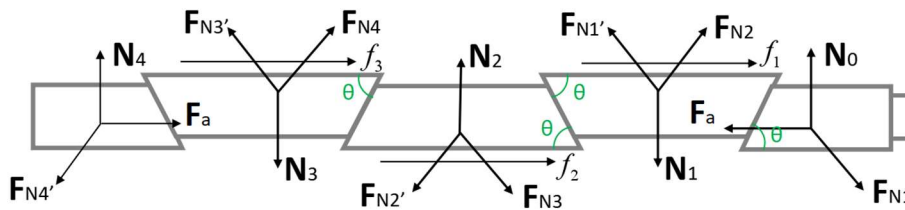


Fig. 2 Force Analysis Schematic of a 5-Segment Wedge Lock Strip in the Locked State

Based on the force analysis schematic, the following relationships are derived from the force equilibrium theorem[4]:

$$F'_{N1} = F_{N1} = F_{N2} = F'_{N2} = F_{N3} = F'_{N3} = F_{N4} = \frac{F_a}{\tan\theta} \tag{1}$$

$$N_1 = N_2 = 2 \frac{F_a}{\tan\theta} \tag{2}$$

$$N_3 = 4 \frac{F_a}{\tan \theta} \quad (3)$$

Where: F_a is the preload force of the head screw; $F_{N1}, F_{N1}', F_{N2} \dots$ is the interaction force generated via wedge surfaces between slider segments; $N_1, N_1 \dots$ is the normal force exerted by the equipment slot on the slider.

$f_1, f_2 \dots$ s the friction force exerted by the contact surface of the equipment slot on the slider. According to the friction formula and Equations (2) and (3), it follows that:

$$f_1 = f_2 = \mu \cdot N_1 = 2\mu \cdot \frac{F_a}{\tan \theta} \quad (4)$$

$$f_3 = \mu \cdot N_1 = 4\mu \cdot \frac{F_a}{\tan \theta} \quad (5)$$

From Equations (4) and (5), the clamping force F_{Lock} of the wedge lock strip is:

$$F_{Lock} = f_1 + f_2 + f_3 = 8\mu \cdot \frac{F_a}{\tan \theta} \quad (6)$$

Similarly, the clamping force of a 3-segment wedge lock strip can be derived as:

$$F_{Lock} = 4\mu \cdot \frac{F_a}{\tan \theta} \quad (7)$$

This clamping force constitutes a critical performance parameter of the wedge lock strip.

2.2 Environmental Testing Requirements for Avionics Equipment.

Table 2. Vibration Test Conditions[5]

Test Type	Frequency (Hz)	Sweep Rate	Acceleration Power Spectral Density(g^2/Hz)
Standard Random Vibration	10-2000	1 oct/min	0.0001-0.1 (0.74-7.94Grms)
Enhanced Random Vibration	10-2000	1 oct/min	0.0001-0.1 (1.48-11.33Grms)
Standard Sine Vibration	10-500	1 oct/min	0.0001-0.1
Enhanced Sine Vibration	10-500	1 oct/min	0.0001-0.1
Short-Duration High-Level Vibration	10-250	0.167Hz/sec	0.001-1

Avionics equipment operates under extremely harsh and complex environmental conditions, including intense mechanical vibration and shock. As the core mechanical fastening component in avionics systems, wedge lock strips primarily secure equipment to racks or rails. Their performance

directly impacts the reliability and safety of the equipment in such demanding environments. The selection, design validation, and final application of lock strips must ensure compliance with DO-160G testing requirements. Environmental test conditions critically relevant to lock strip selection focus on vibration and shock. Specify the respective test conditions for vibration and shock, see Table 2 and Table 3 [5].

Table 3. Vibration Test Conditions[5]

Test Type	Peak Shock Acceleration	Nominal Duration(ms)
Standard Operational Shock	6	11
Low-Frequency Operational Shock	6	20
Crash Safety Shock	20	11
Low-Frequency Crash Safety Shock	20	20

3. Engineering-Oriented Wedge Lock Strip Selection Methodology

3.1 Selection Methodology

To ensure structural reliability, environmental adaptability, and full lifecycle safety of avionics equipment under dynamic loads, a systematic wedge lock strip selection process must be established. The methodology is detailed below:

- (1) Equipment Requirement Analysis: Delineate the avionics equipment’s functional module layout, interface relationships, installation locations, and constraints (e.g., spatial limitations, thermal paths, EMC requirements). Define the clamped module weight, lock strip mounting position, and dimensional specifications (e.g., lock strip length, module slot geometry). Based on this, preliminarily determine the effective working length range of the lock strip.
- (2) Material Type Selection: Conduct preliminary material screening based on equipment requirements. Prioritize proven aviation-grade metallic materials (e.g., high-strength aluminum alloys, corrosion-resistant stainless steel), balancing load capacity, thermal conductivity, manufacturability, and compatibility with other components. Simultaneously evaluate cost and supply chain feasibility.
- (3) Preliminary Clamping Force Calculation: Screen candidate models using lock strip length and material properties. Calculate the theoretical clamping force using supplier-provided parameters (e.g., tightening torque, material friction coefficient) as the baseline for subsequent selection.
- (4) Environmental Test Condition Extraction: Determine the lock strip’s extreme load requirements, including module self-weight and vibration/shock test loads, per DO-160G standards and installed environment. Identify the most severe test conditions, e.g., maximum vibration level, shock pulse, to avoid redundant calculations.
- (5) Module Inertial Force Calculation: Apply the static equivalent method to compute inertial forces using module mass and the most severe environmental acceleration a :

$$a = 1.4 \cdot G \cdot g \tag{8}$$

Where: a denotes the acceleration induced by vibration or shock; G is Maximum vibration/shock intensity from test spectrum; g is Gravitational acceleration constant (9.8 m/s^2); For static simulation analysis under vibration/shock conditions, a safety factor of 1.4 is recommended.

- (6) Safety Factor Validation: Given that vibration/shock amplifies stress, the aviation industry recommends a safety factor range of 3–5. Use this range to inversely verify and determine the required clamping force for the selected lock strip.

This process integrates equipment requirements, environmental conditions, material properties, and safety margins, delivering an airworthiness-compliant wedge lock strip selection solution for avionics equipment.

3.2 Engineering Application

An avionics unit (weight <5kg, ARINC 600 compliant) was installed in the console of a fixed-wing aircraft. Environmental testing followed DO-160 standards: Vibration Category S (B3), Operational Shock and Crash Safety Category B. For a target module (weight <1.2kg, PCB dimensions: 175×230mm), wedge lock strip selection proceeded as follows:

(1) Equipment requirements: Lock strip mounting allowance 5–15mm, so effective length $L=200\text{--}220\text{mm}$; forced-air cooling required high-thermal-conductivity material; surface conductive treatment: ground resistance $<10\text{m}\Omega$. 5 candidates prescreened.

(2) Material selection: 6061-T6 aluminum alloy (yield strength $\geq 240\text{MPa}$, thermal conductivity $\geq 180\text{W/m}\cdot\text{K}$, hard anodized). 4 matched models.

(3) Clamping force calculation: Based on Al-Al friction coefficient $\mu=0.15$ and supplier screw parameters:

$$0.68\text{N}\cdot\text{m model} : F_a = 4 \times 0.25 \times 680 / (0.16 \times 3) = 1416.67\text{N} ;$$

$$0.60\text{N}\cdot\text{m model} : F_a = 4 \times 0.25 \times 600 / (0.16 \times 3) = 1250\text{N} .$$

(4) Extreme environmental load:

Table 4. Environmental Test Conditions[5]

Test Type	Category	Parameter Requirements	Equivalent Acceleration
Standard Vibration	S(B3)	5–500 Hz sine sweep, amplitude $\pm 1.5\text{ mm}$	$G_{vib} = 6g$
Operational Shock	B	Half-sine wave, peak 20g, pulse width 11 ms	$G_{shock} = 20g$

The most severe load condition is defined as the shock scenario with $G_{max} = 20g$.

$$(5) \text{Module inertial force: } F = m \cdot (G_{max} \times g) \cdot \gamma = 1.2 \times (20 \times 9.8) \times 1.4 = 329.28\text{N} .$$

static simulation safety factor $\gamma=1.4$.

(6) Safety Factor Validation: Applying the aviation safety factor $\eta=4$, the required clamping force is calculated as $F_r = \eta \times F_i = 4 \times 329.28 = 1317.12\text{N}$.

So the model with a clamping force of 1416.67 N is selected.

4. Conclusion

The systematic wedge lock strip selection method proposed in this paper establishes a closed-loop decision model covering the entire design-implementation-validation lifecycle. This is achieved by integrating physical constraints of equipment, load spectrum mapping of environmental conditions, material property adaptation, and airworthiness safety verification.

Validated through empirical testing on an ARINC 600 compliant avionics device, this method:

1) Ensures a safety factor ≥ 4 with precision

2) Enhances decision-making efficiency by 40% (benchmarked against traditional methods)

This approach fundamentally resolves the core conflict in experience-based selection: the absence of a locking force-vibration coupling mechanism. It delivers a high-reliability and lightweight fastening solution for Integrated Modular Avionics (IMA) systems, extendable to other vibration-resistant

fastening applications in modular electronic equipment. If you follow the “checklist” your paper will conform to the requirements of the publisher and facilitate a problem-free publication process.

References

- [1] HE En, CHENG Hao-yue, LAI Tian-hua, et al. Research of the heavy wedge lock[J]. Journal of Mechanical & Electrical Engineering, 2020, 37(6) : 715 -718.
- [2] SJ 20382-2007, Specification for Wedge Locking Devices [S]. Beijing: China Electronics Standardization Institute, 2007.
- [3] HU Yuqin, TAO Qiufan, DENG Zongbai. Mechanical performance analysis of wedge locking devices[J]. Water Resources and Electric Power Machinery, 2007, (12): 203–206+210.
- [4] ZHOU Xiaodong. Nonlinear dynamic characteristics analysis of wedge lock structure for electronic equipment[J]. Electro-Mechanical Engineering, 2012, 28(03): 16–19+30.
- [5] RTCA. DO-160G Environmental Conditions and Test Procedures for Airborne Equipment[S]. Washington, D.C.: RTCA, Inc., 2014.