Research on the Transmissibility of Wire Rope Insulators as Damping Equipment on the RX 200 Rocket Payload

Agus Budi Djatmiko[1] , Ediwan, Ronald[1], Gunawan Putra[1]

[1]Rocket Technology Center, National Institute of Aeronautics and Space (LAPAN), Indonesia

e-mail: agusbudi60@gmail.com

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Abstract

Wire rope insulator or steel wire rope insulator has applications for vibration isolation in equipment and structures in many industrial machinery. Steel wire rope insulators can also be used as suitable equipment to dampen vibrations in rocket loads. The disturbance acceleration as the excitation caused by the combustion process on the rocket can cause a vibration with a large amplitude which results in damage to the rocket's payload structure and the electronic equipment on the rocket's payload cannot work as desired. Based on the experience of electronic equipment, it will be damaged if the disturbance acceleration of 3 g acting on the rocket is not reduced, for this reason a vibration damping device is designed, the apparatus consists of several stainless steel wire ropes tied between two parallel binders arranged in such a way as to provides a damping effect on the rocket's payload. A wire rope insulator consists of several stainless steel wire ropes tied between two parallel straps. One application of this type of wire rope insulator is to isolate the vibrations that occur in the rocket, so that it does not interfere with the performance of the electronic equipment on the rocket's payload. Electronic equipment is used to determine the position of the rocket and its stability. In this study, the wire rope material used is stainless steel with σ_{yield} = 350 e+6 N / m2 with a diameter of d = 3 mm.

The research objective of the vibratory damper of wire rope insulators was to determine the magnitude of the transmissibility of the ruffler during and after resonance. Transmissibility (TR) is the ratio of the force transmitted to the disturbing or excitation force.

The results of the research on a damper with a disturbance acceleration of 3 g at resonance $(\omega/\omega_n = 1)$, obtained the transmissibility value (TR) = 2.54, the spring stiffness k = 200537.3 N/m and the damping coefficient c = 331.5 N/m/sec, then after conditions $\omega/\omega_n = 2.38$ obtained transmissibility (TR) <1 This shows that the damper with steel wire isolator is good enough to dampen vibrations in the RX 200 rocket payload.

Keywords: *Wire rope isolator, Resonance, Transmissibility*

Nomenclature

m	=	mass of payload, kg
k	=	isolator vibration stiffness, N/m
c	=	wire rope damping coefficient, N/m/s
Fo	=	the excitation force of the rocket, N
F_T	=	force transmitted by rocket payload, N
kx	=	force of compression, (N)
x	=	the deviation from the equilibrium position, m
TR	=	Transmissibility
A_0	=	acceleration of disturbance (m / sec2)
A_T	=	the acceleration transmitted to the rocket's payload (m / sec2)
ω	=	frequency of work of rocket (rad / second)
ξ	=	damping factor
ω_n	=	natural frequency (rad / second)

$m\ddot{x}$ = inertia force, (N)
$c\dot{x}$ = damping force (N)

1. Introduction

Vibration becomes intolerable, the isolation system is applied to cut off the path of the vibration to enhance the safety of the receiver. A general isolation system has two main components namely, Stiffness (K) and Damping (C) Firstly, the stiffness of the isolation system provides the restoring force and also influences the natural frequency of the isolated system. The lower value of transmissibility can be achieved by decreasing the stiffness which results in shifting the natural frequency of the system to a lower value (Balaji et al., 2016)(Ledezma-Ramirez et al., 2016). Secondly, the damping component of the isolator enables the energy dissipation of the external excitation to suppress it. The amount of damping required is subjective and varies with respect to applications. Vibrations and shocks are studied using various techniques and analyzed to predict their detrimental effect on the equipment and structures. In many cases, the vibrations are unavoidable, but it will be within tolerable limits. In other cases, where the vibration becomes intolerable, it is required to analyse the system for the effects of vibrations and improve the mechanical properties or in a place where are system design restricted in improving mechanical properties, it is then required to add an isolation system to counter the vibrations (Ledezma-Ramirez et al., 2012)(Balaji et al., 2015). The application of vibration isolation system requires an understanding of the vibration control components, namely, source, path and receiver of the vibration (Balaji et al., 2016)(Ledezma-Ramirez et al.,2016).

Vibration is undesirable in many domains, especially engineering systems such as vibrations in rocket payloads and methods have been developed to prevent the transfer of vibrations to such systems (Voss et al., 2009). In other cases, where the vibration becomes intolerable, the isolation system is applied to cut off the path of the vibration to enhance the safety of the receiver (Balaji et al., 2015)(S. Pagano & S. Strano, 2013). A general isolation system has two main components namely, Stiffness (K) and Damping (C) (Ledezma-Ramirez et al., 2014)(Rao, 2007). Firstly, the stiffness of the isolation system provides the restoring force and also influences the natural frequency of the isolated system. The lower value of transmissibility can be achieved by decreasing the stiffness, which results in shifting the natural frequency of the system to a lower value (Puff et al., 2015). Over the past few years, many variant and isolating devices have been designed to reduce vibration or isolate structures from unwanted vibrational energy. Among these devices, wire rope insulators are noted for their high performance in vibration and shock isolation. They have found many insulation applications in aerospace systems and other sensitive equipment. One application of this type of wire rope insulator is to isolate the vibrations of electronic equipment present in the rocket's payload(Voss et al., 2009)(Rao, 2007)

Wire Rope Isolators (WRI), an elastic stiffness and damping, has become the subject Passive systems are of two types, linear and nonlinear system. The linear systems earlier developed displacement relation, and they are effective only when less than the external excitation frequency. However, in the cases such as low frequency vibrations which can the linear isolation system limitations can be overcome using vibration isolators and comprehensive survey of recent n which many cited stiffness are of great benefit in vibration linear behavior in both Passive systems are of two types, linear and nonlinear system. The linear systems were earlier developed behavior in force-displacement relation, and they are effective only when less than the external excitation frequency. However, in the cases such as motions, shocks or impact loads, there can be low frequency vibrations s. However, the linear isolation system limitations can be overcome using Several authors have developed different types of nonlinear vibration isolators and investigated the unique dynamic behaviors (Ledezma-Ramirez et al.,2016) (Patent, 2014).

A wire rope insulator consists of several stainless steel wire ropes tied between two parallel straps. Due to the shear friction between the wire strands and the internal friction of the cable, the insulator exhibits nonlinear hysteresis behavior. Apart from mechanical damping characteristics in the three main directions, they have other advantages such as attenuating strong shocks, aging and thermal insensitivity as well as low cost. For the purpose of predicting the vibration response and for better use and design of insulation systems with wire rope insulators, it is necessary to accurately identify their hysteresis restoring strength under static and dynamic loads. (Ledezma-Ramirez et al.,2016)(Balaji et al., 2015)(ITT Enidine Inc, 2014).

2. Methodology

The research was started from the design of the device, looking for the disturbance acceleration data, the damping factor, then the equation of motion analysis of the vibration damper. After that, determine the magnitude of the squeezing constant k (N / m). After that, look for the vibration transmissibility equation to determine the magnitude of the acceleration transmitted to the rocket's load, and finally the research on the transmissibility of the vibration damper on the RX 200 rocket charge at the time of resonance.

The research was conducted at the Vibration Test Laboratory at the LAPAN Ranca Bungur Satellite Technology Center, Bogor.

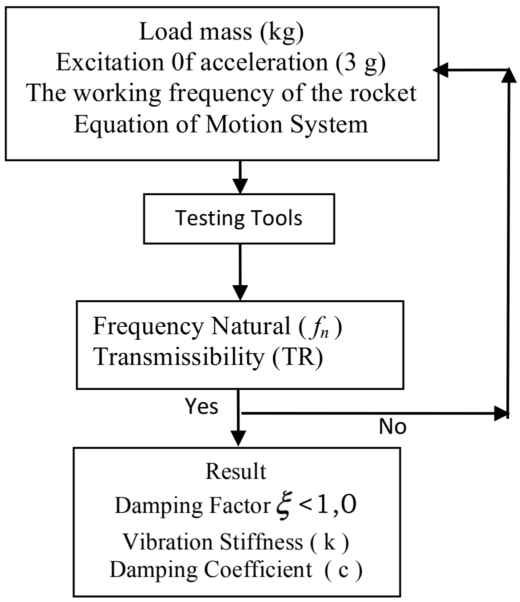

Figure 2-1: Flow chart of vibration damper testing

2. 1. Problem Definitions

The phenomenon of vibration occurs at the time of rocket's flight. This will cause problems in the body and systems that exist in the rocket due to the forces that arise due to the vibration phenomenon. This should be a concern because if left unchecked, the rocket will fail not only in its electronic system, but also in its structure, indeed the rocket must have a vibration insulator system that will dampen the forces acting on the vibration phenomenon.

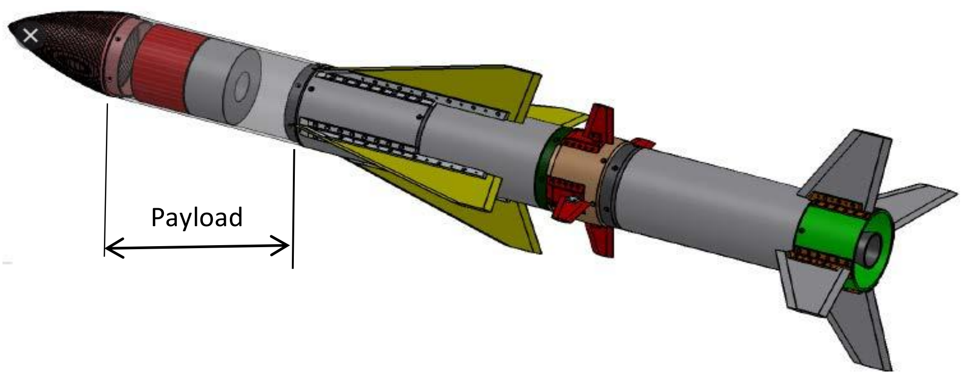

Figure 2-2: Rocket RX 200

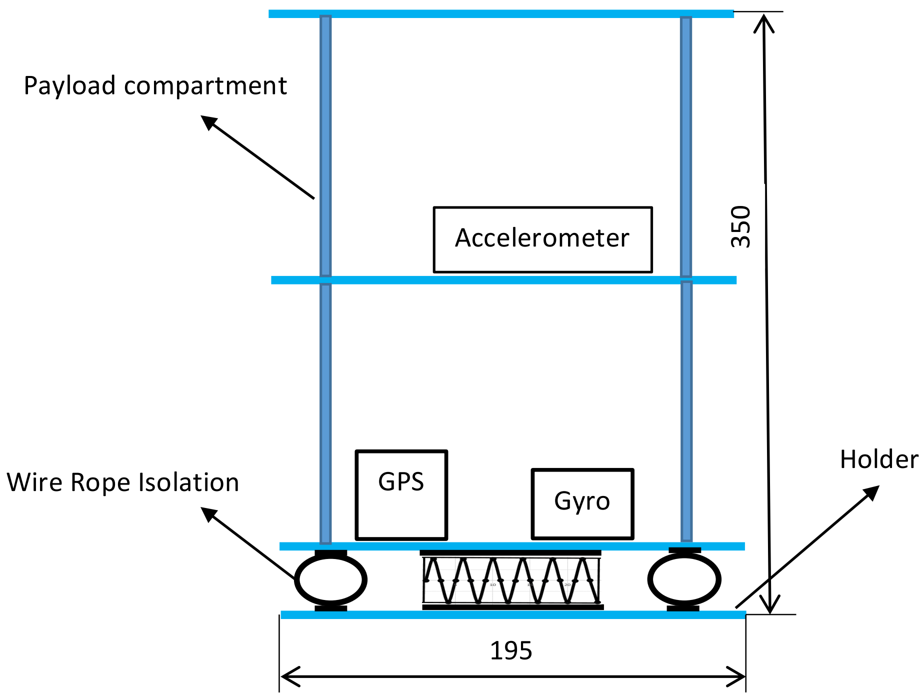

Figure 2-3: Payload System

2. 2. Method

The system is simplified as vibrational elements, namely mass, stiffness, and damping which are analogous to the mass of the object, spring, and damper, then the equation of motion of the rocket system is determined which is derived from all the elements in the rocket system. From this equation of motion, an important characteristic of the vibration system will be obtained, namely the damping factor and transmissibility (Rao, 2007).

3. Result and Analysis

The motion equation for the vibration dampening system model in Figure 2-3 is:

$$m\ddot{x} + c\dot{x} + kx = F_o(t) \tag{3-1}$$

$$-m\omega^2 X + c\omega X + kX = F_o \tag{3-2}$$

$$X = \frac{F_o/k}{\sqrt{\left[1-\left(\frac{\omega}{\omega_n}\right)^2\right]^2 + \left(2\xi\frac{\omega}{\omega_n}\right)^2}} \tag{3-3}$$

The solution to the equation is F_o (t) = 0. where the equation will give an understanding of the role of damping with the homogeneous equation.

The force that passes the load through the springs and dampers is

$$F_T = \sqrt{(kX)^2 + (c\omega X)^2} \tag{3-4}$$

And the excitation or disturbance force F_o of the rocket in the force balance system in the rocket charge suppressor system is given by the following equation:

$$F_0 = \sqrt{(kX - m\omega^2 X)^2 + (c\omega X)^2} \tag{3-5}$$

Finally transmissibility (TR) can be determined as

$$\frac{A_t}{A_O} = TR = \frac{\sqrt{1 + \left(2\zeta \frac{\omega}{\omega_n}\right)^2}}{\sqrt{\left[1 - \left(\frac{\omega}{\omega_n}\right)^2\right]^2 + \left[2\zeta \frac{\omega}{\omega_n}\right]^2}} \tag{3-6}$$

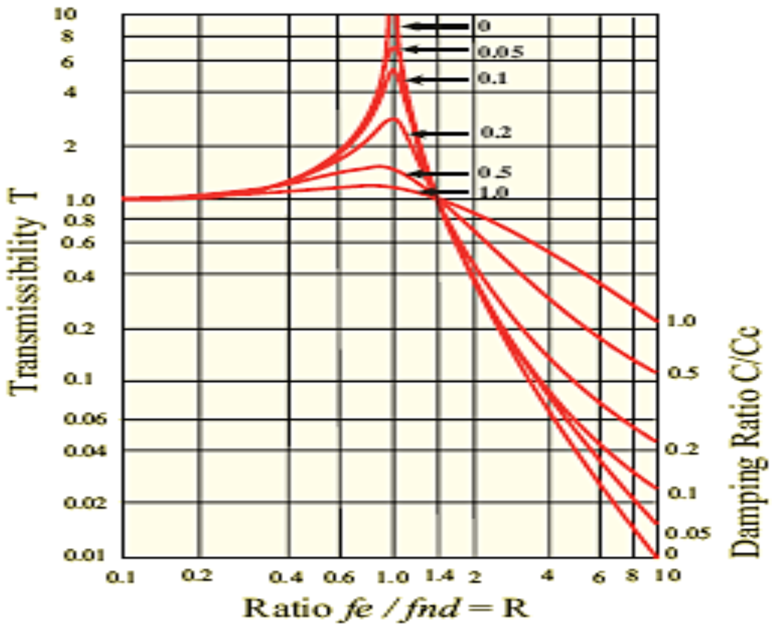

Figure 3-1: The relationship between transmissibility to the frequency ratio (Rao, 2007).

Figure 3-2: Wire Rope Isolation

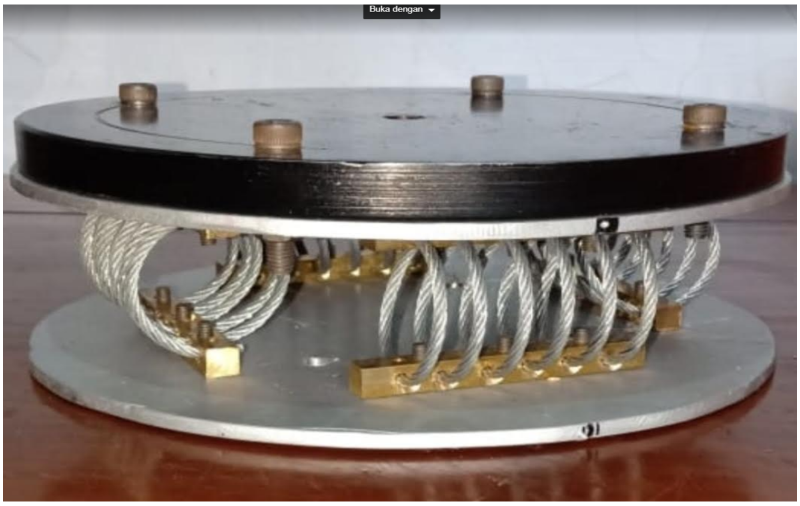

Figure 3-4: Wire Rope Isolation of RX 200 LAPAN Payload

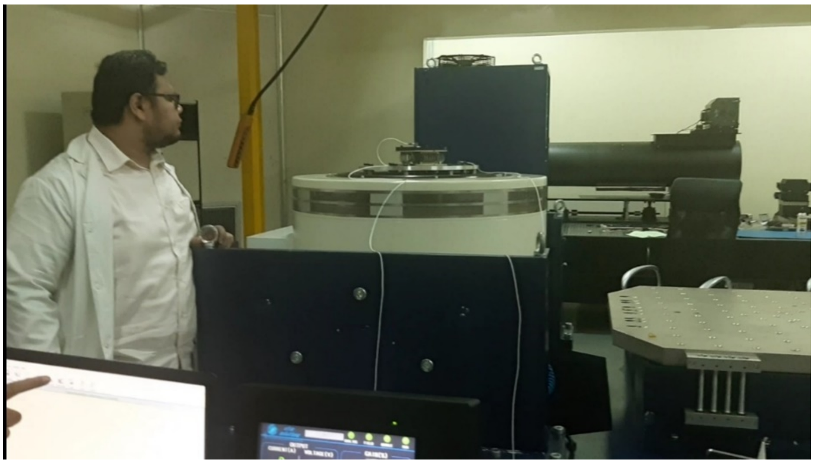

Figure 3-5: Testing of Wire Rope Isolation of RX 200 LAPAN Payload

Research data :
Wire rope diameter, dr = 3 mm
Wire rope circle diameter, dl = 30 mm
Material: Stainless steel wire rope with σ_{yield} = 350 e6 N / m2.
Load m = 2.8 kg
G force = 3 g

Table 3-1: Vibration Testing Result

f_n	G_O			G_T		*TR*
43.9207	3	3.02223	3.02233	7.68886	1.000033088	2.544101541
44.0485	3	3.02251	3.0224	7.70078	0.999963606	2.547809602
105.33	3	3.00949	3.00951	3.01184	1.000006646	1.000780863
105.637	3	3.01005	3.01006	3.001	1.000003322	0.996993405
105.944	3	3.01017	3.01016	2.9903	0.999996678	0.993399044

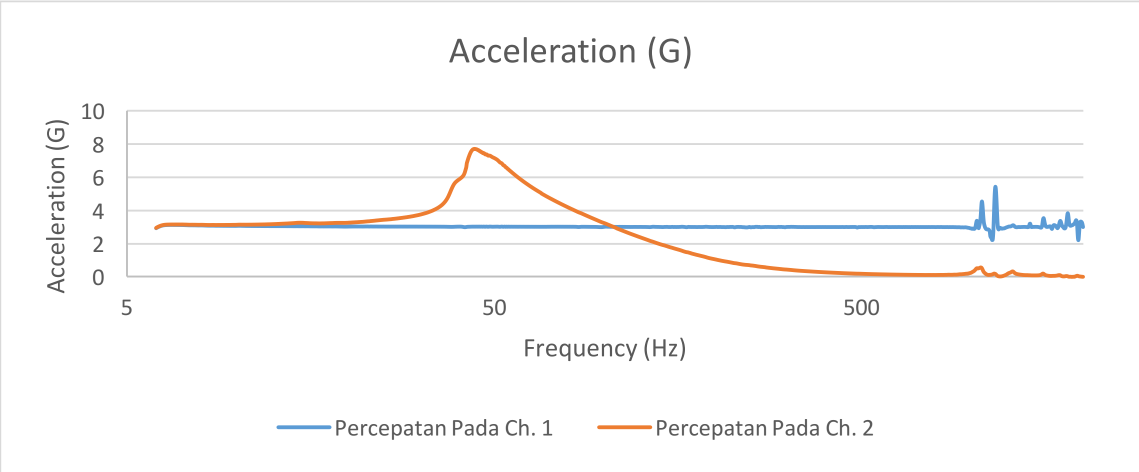

Figure 3-6: Natural Wire Rope Isolation RX 200 Frequency Testing Graph

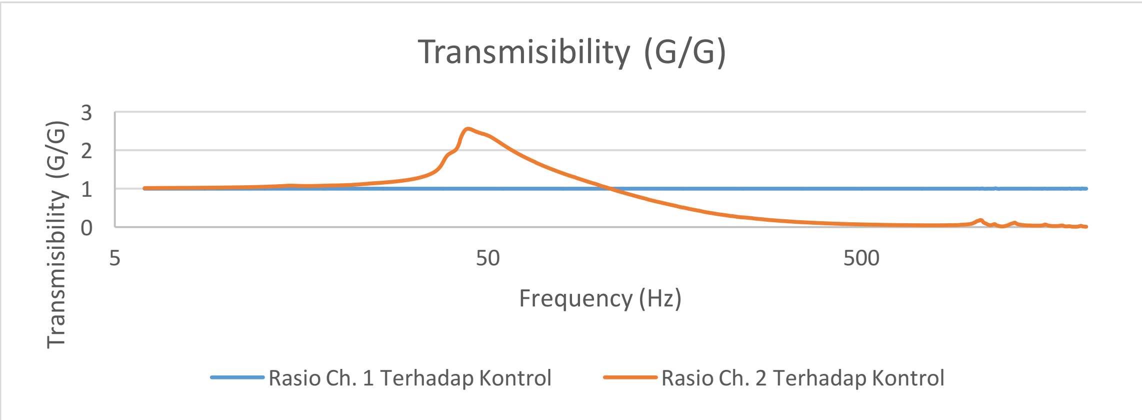

Figure 3-7: Transmissibility Wire Rope Isolation RX 200 Testing Graph

Table 3-2: Test results and calculations for wire rope isolation

Properties	Value (unit)
Natural Frequency (f_n)	44,485 Hz
Transmissibility Resonance (TR)	2,54
Viscous Damping Ratio (ξ)	0,214
Damping Coefficient (c)	331,5 (N/m/second),
Isolator Vibration Stiffness (k)	200537,3 (N/m)
Critical Damping (c_c)	1549, (N/m/second),

4. Conclusions

From the test results of wire rope isolation as a vibration dampening device on the RX 200 rocket load, it can be said to be quite satisfying because at the time of resonance where the transmissibility of TR = 2.54, the vibration dampening device can work as desired and does not experience damage and the wire rope isolation shows as a good damper after a frequency of 105.637 Hz, has a transmissivity (TR) smaller than one. In addition, wire rope isolation on the RX 200 rocket load also has a damping factor ξ = 0.214, which is fulfilled as a clamp tool because ξ <1 (under-damped system)

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Contributorship Statement

Agus Budi Djatmiko developed the simulation, designed the method, analyzed the results, Ediwan and Ronald G.P. prepared the testing method and manuscript.

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