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VIBRATION DISTURBANCE DAMPING SYSTEM DESIGN TO PROTECT PAYLOAD OF THE ROCKET

PERANCANGAN SISTEM PEREDAM GANGGUAN GETARAN UNTUK MELINDUNGI BEBAN-GUNA ROKET

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Abstract

Rocket motor generates vibrations acting on whole rocket body including its contents. Part of the body which is sensitive to disturbance is the rocket payload. The payload consists of various electronic instruments including: transmitter, various sensors, accelerometer, gyro, the embedded controller system, and others. This paper presents research on rocket vibration influence to the payload and the method to avoid disturbance. Avoiding influence of vibration disturbance can be done using silicone gel material whose typical damping factors are relatively high. The rocket vibration was simulated using electromagnetic motor, and the vibrations were measured using an accelerometer sensor. The measurement results were displayed in the form of curve, indicating the vibration level on some parts of the tested material. Some measurement results can be applied to determine the good material to attenuate vibration disturbance on the instruments of the payload.

Key words: motor, rocket, vibration, payload, silicone.

Abstrak

Motor roket dapat menimbulkan getaran yang menggetarkan roket beserta isinya. Bagian yang rentan mengalami gangguan adalah beban-guna roket. Beban-guna ini terdiri dari berbagai peralatan elektronik seperti: transmitter*, macam-macam sensor, akselerometer,* gyro, embedded controller system*, dan lain sebagainya. Pada makalah ini disajikan penelitian pengaruh getaran motor roket terhadap beban-guna dan cara mengatasi gangguan tersebut. Untuk mengatasi pengaruh gangguan getaran dapat dilakukan dengan menggunakan bahan* silicone gel. Silicone gel *dipilih sebagai bahan isolator karena memiliki faktor redaman spesifik yang relatif tinggi dibandingkan dengan beberapa bahan lain. Getaran motor roket disimulasikan menggunakan motor listrik dan diukur menggunakan sensor akselerometer. Hasil pengukuran ditampilkan dalam bentuk kurva, yang menunjukkan level getaran pada beberapa bagian benda uji. Hasil dari beberapa percobaan dapat digunakan untuk menentukan bahan peredam yang baik untuk mengurangi getaran yang mengganggu instrumen pada beban-guna.*

Kata kunci: motor, roket, getaran, beban-guna, silicone gel.

I. INTRODUCTION

An important part in rocket is the electronic payload named embedded control system which consists of microprocessor, sensors, analog and digital circuits, transceiver radio, circuit wiring and power supply.

The entire parts of the payload must be protected from disturbances occurring mainly at the time of launching. The most influencing disturbances are held along propellant burning time, as shown in Figure 1. Most of the time, very significant shocks and vibrations occurred due to the rocket motor firing. Frequently, problem occurs at the launching, causing the electronic parts of the payload not to function suddenly while the motor is still firing. These problems happen frequently in launching of a big type rocket such as RX-250, RX-320 and RX-420 [11]. To resolve the problem it is necessary to have an absorption system to reduce vibration and shock disturbances. The absorption system can be used to protect the embedded system from various shocks, vibrations and acceleration forces, not only during burning time but also along the

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Figure 1. Rocket launching in burning time.

whole rocket trajectory. The objective of this studi is to design vibration disturbance system to protect payload of the rocket. By this design, it is expected that the payload will properly work along whole trajectory, at least during burning time.

II. DISCUSSION AND THEORY

In rocket launching, disturbances are capable to damage the embedded control system. These disturbances consist of two components i.e. acceleration of vibration and linear acceleration generated in motor thrust. In several LAPAN (Indonesian National Institute of Aeronautics and Space) rockets, linear acceleration achieved is up to 20 G [11]. In line with the fact that the dominant disturbance constitutes vibration the research presented in the paper is mainly focused on the disturbance caused by vibration.

A. Vibration

Vibration, which is back and forth moving in a certain time interval, is related to the oscillating move of a body and forces relating to the movement. A body hanged on a spring can be used to generate a vibration. All bodies owning mass and elasticity are capable to vibrate. Hence, almost all engineering machines structures experience vibration. Vibration is classified into two classes, free vibration and forced vibration.

1) Free vibration

Free vibration occurs if a system is oscillating due to its internal forces. A system which is free vibrating will oscillate in one or several of its natural frequencies. All systems owning mass and elasticity can freely vibrate without external forces.

2) Force vibration

Force vibration is vibration caused by external stimulating force. If the force is oscillating then the system is forced to vibrate on the stimulating frequency. If the stimulating frequency is the same as one of the system natural frequencies, then a resonance will occur. This resonance can be great and dangerous. It can damage to a big structure like aircraft wing, bridge, or building.

In force vibration, oscillation can be regular or irregular repeat. If the move is repeated in the same duration then the move is called periodical vibration and the repeating time is called period of the oscillation. In periodical vibration, position as function of time can be expressed as x(t) = x(t+T) where T is period of the oscillation. Physical model of the oscillation system is shown in Figure 2.

Mathematical model can be expressed using equation of vertical force balance:

$$ma(t) + kx(t) \tag{1}$$

Supposing position as function of time is:

$$x(t) = A\sin(\omega t) + B\cos(\omega t)$$

Velocity of the move:

$$v(t) = \frac{dx}{dt} = \omega A\cos(\omega t) - \omega B\sin(\omega t)$$

Acceleration of the move:

$$a(t) = \frac{dv}{dt} = -\omega^2 A\sin(\omega t) - \omega^2 B\cos(\omega t)$$

$$a(t) = -\omega^2 x(t) \tag{2}$$

Then from equation (1) and (2) we obtain:

$$m\left(-\omega^2 x(t)\right) + kx(t) = 0 \tag{3}$$

$$(k - m\omega^2)x(t) = 0 \tag{4}$$

Vibration occurs if $x(t) \neq$, then $(k - m\omega^2) = 0$ and natural frequency can be expressed as:

$$\omega_n = \sqrt{\frac{k}{m}} \tag{5}$$

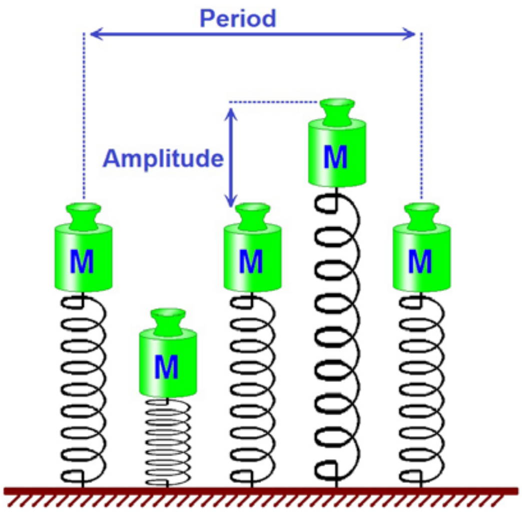

Figure 2. Physical model of the oscillation system [1].

Or:

$$f_n = \frac{1}{2\pi}\sqrt{\frac{k}{m}} \quad (6)$$

Where

ω_n : Natural frequency (radian per second)
f_n : Natural frequency (Hertz)
k : Stiffness (Newton per meter)
m : Mass of load (kilogram)

The value of natural frequency is important in damping system design [5]. From the fact that resonance between disturbance signal and damping system can be very dangerous, then the natural frequency of the damping system must be lower than force frequency of the disturbance signal. And further, lowering the natural frequency of the damping system can assure the damping condition i.e. the displacement of the damping vibration will be less than the displacement of the disturbance.

Transmissibility, which is defined as ratio of the displacement of the damping vibration to the displacement of the disturbance vibration, is typically depicted for various damping conditions in Figure 3.

It is seen from Figure 3 that if transmissibility is less than one then the curves will be included in the region of isolation and if the transmissibility is greater than one then the curves will be included in the region of amplification. It can also be seen that if frequency ratio is greater than $\sqrt{2}$ then the curves will be included in the region of isolation and if the transmissibility is less than $\sqrt{2}$ then the curves will be included in the region of amplification. The point which is commonly called the resonant point occurs if frequency ratio is one, where the transmissibility will be at its maximum value.

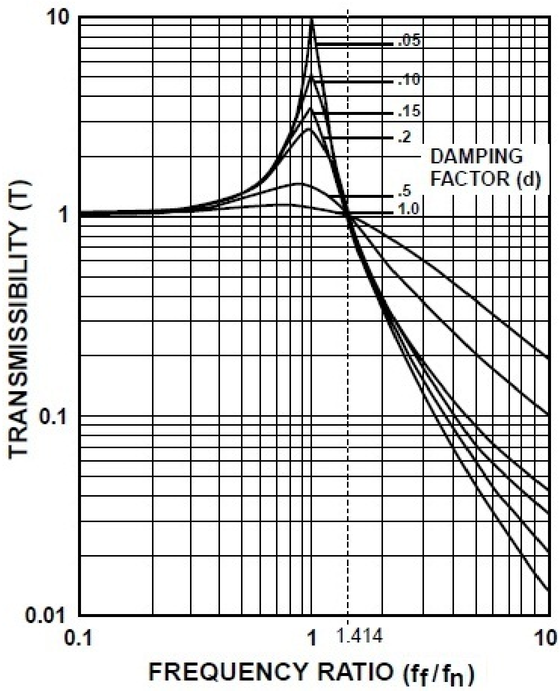

Figure 3. Typical transmissibility curves [12].

Internal mechanical energy which constitutes potential energy and kinetic energy of the spring in the damping condition is decreasing. It means that a part of the mechanical energy is converted to heat. Further, the damping (d) is defined as the dissipation of energy by conversion to heat. The typical transmissibility curves for various damping conditions are shown in Figure 3, and Figure 4 presents damping factors for some typical materials.

B. Shock

A rocket machine generates a thrust force. Shape of the thrust is normally a pulse forming a square wave form. Duration of the pulse which is called burning time for several LAPAN rockets were environ ten seconds. Note that for ten seconds of burning time, the total duration of whole trajectory can achieve up to two hundred seconds. Shock occurs at the beginning and the end of the pulse. At the beginning, the shock constitutes transient between zero thrust and nominal thrust, and at the last of the pulse, the shock constitutes transient between nominal thrust and zero thrust. In the research presented in this paper, to solve the shock problems spring and mass system were used. The important step in designing a spring and mass damping system is the step to select natural frequency of the damping system. Equation 7 can be applied to design damping system especially in determining the natural frequency:

$$G_t = \frac{V(f_n)}{g} \quad (7)$$

Where

G_t : Transmitted shock (unity)
V : Velocity (meter per second)
f_n : Natural frequency (hertz)
g : Acceleration due to gravity ($9.81 m/sec^2$)

Typical Damping Factors

Material	d
Natural Rubber	.05
Neoprene	.05
Felt and cork	.06
Butyl	.10
Highly damped silicone	.13+
Friction damped spring	.30+

Figure 4. Typical damping factors [12].

The associated dynamic deflection (Δd) can be determined by:

$$\Delta d = \frac{V}{2\pi f_n} \tag{8}$$

Where

Δd : Associated dynamic deflection (meter)
V : Velocity (meter per second)
f_n : Natural frequency (hertz)

It is not very different between protecting the equipment in rocketing and in free-fall drop from a certain height. So far we have found that to protect the equipment in free-fall drop we need to calculate:

- A system's natural frequency,
- A dynamic deflection,
- A stiffness of dynamic system.

All of these three conditions must be met to assure that no more than the acceleration value limit is transmitted to the equipment.

Note that the dynamic stiffness (K) found is the *system* stiffness. It must be divided by the number of mounts to determine the stiffness required per mount. If both vibration and shock are present, both must be considered. Quite often the final solution is a compromise.

C. Vibration and Shock Problem in Rocket

In space technology rocket is classified as a vehicle. In contrast to the aircraft vehicle that its critical moment is when landing, critical moment of the rocket is when launching. Problems appearing in a rocket launching, mainly for the large diameter rocket having complex payload, is vibration and shock acting on whole rocket body. This uncontrolled force disturbance working at the embedded control system can cause deflection to the mission during the launching. In RX-320 rocket launching in 2009, the launching mission deflection still existed [11]. The payload functioned just for several seconds, while motor was still firing, then it was suddenly not working properly. This problem does not occur only to LAPAN's rocket, but also to rockets belong to several foreign institutes of aeronautics, even NASA's [2, 3, 4]. The shock and vibration were seriously disturbing NASA's rockets. Rocket vibration oscillates in the range from zero to 2000 Hz of frequency, and shock action begins while motor starting until separation time. At separation time the acceleration valued environ 20 G [6, 7].

D. Vibration and Shock Absorption

Absorption of vibration and shock can be established by applying silicone gel material, as shown in Figure 5. The material was selected in line with the fact that silicone material has high typical damping factors more than one of several other materials as tabled in Figure 4. The same method and material were also utilized in vibration and shock absorption in the laptop to protect the hard disk from vibration and shock during usage and from accidental fall as shown in Figure 5 [8, 10].

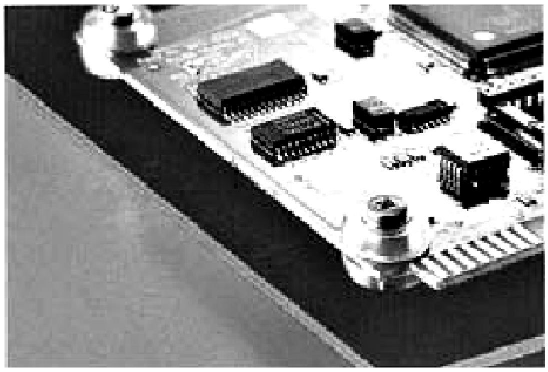

Figure 5. Silicone gel damping application [10].

Absorption method established in rockets usually applied is by using metal spring combined with silicone gel [8, 9]. The spring was not made in spiral form to avoid unbalance while being loaded, as shown detail in Figure 6 [8, 13]. Instead, the form was omega.

III. TEST AND OBSERVATION

A. Vibration Test

Testing installation is shown in Figure 7. The tests were done at BPPT (Puspiptek) Laboratory at Serpong. Compartment standard model of RX-200 rocket payload of 4.5 kg of mass was damped using 8 CR2-200 types of Enidine damping, and the PCB was covered in several materials of silicone. Resulting curves are shown in Figure 8. The acceleration was set to be 1 G and the signal disturbance was scanned in 5 Hz - 2000 Hz of frequency

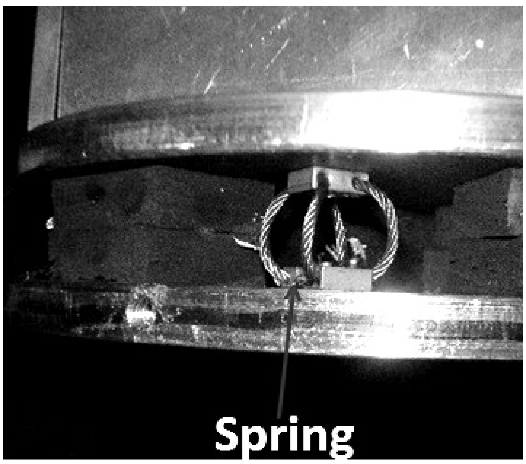

Figure 6. Spring damping application.

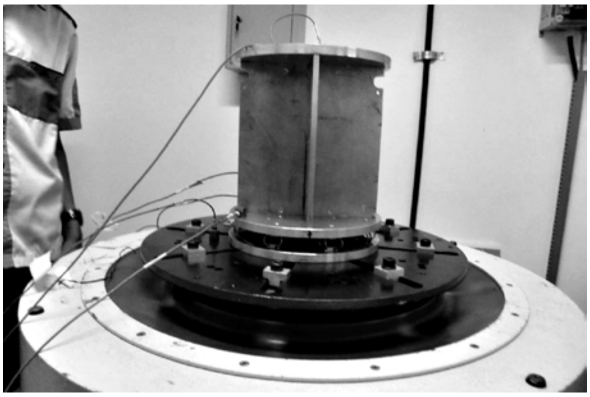

Figure 7. Vibration testing.

B. Observation

Among several curves in Figure 8, just two curves representing signals measured. Curve (1) showed vibration on the outer PCB box while curve (2) showed vibration on the surface of PCB covered by damping material. The other curves were not installed to the sensors.

It was seen that curve (1) and curve (2) had almost the same amplitude at low frequency (80 Hz). At medium frequency (80 Hz - 330 Hz), damped vibration amplitude was greater than one outer side (un-damped). This phenomenon indicated appearing resonance between disturbance signals and damping system having medium natural frequency. On the other hand, at high frequency (330 Hz to 2000 Hz), damped vibration amplitude was falling down under 0.1 G, smaller than signal disturbance amplitude. It meant that the dumping system was relatively good enough and able to reduce 0.9 G of acceleration magnitude.

IV. CONCLUSION

According to the results of discussion, testing, and observation, it can be concluded that the damping system designed was able to reduce the amplitude significantly. From equation (4), the transmissibility T would be 0.1 at 550 Hertz of force frequency. Natural frequency of the damping system could be obtained from equation (7):

$$f_n = \frac{550}{\sqrt{\frac{1}{0.1}+1}} = 166Hz$$

In fact, the disturbance frequency measured was 1000 Hertz. This value of frequency was relatively high enough comparing to the natural frequency, and it was assuring not to interfere to the natural frequency of the damping system.

REFERENCES

[1] Ade Agung Harnawan. (2012, November 28). *Pegas Massa Linier*. [Online]. Available: http://adefisika.wordpress.com/2011/05/08/pegas-massa-linier/

[2] R. Caimi et.al. *Rocket Launch- Induced Vibration*. NASA report.

[3] THE ASSOCIATED PRESS. (2008, January 20). *New Rocket Has Problem With Vibration*. [Online]. The New York Times Published. Available: http://spectrum.ieee.org.

[4] _____________. (2009, September 16). *NASA Identifies Fix for Ares 1 Vibration*. [Online]. Available: www.spacenews.com/civil/fix-for-ares-vibration-issue.html

[5] Mechanical Brothers. (2012, November 28). *Frekuensi Pribadi (Natural Frequency) dan Putaran Kritis (Critical Speed)*. [Online]. Available: http://mechanicalbrothers.wordpress.com/2011/01/08/frekuensi-pribadi-natural-

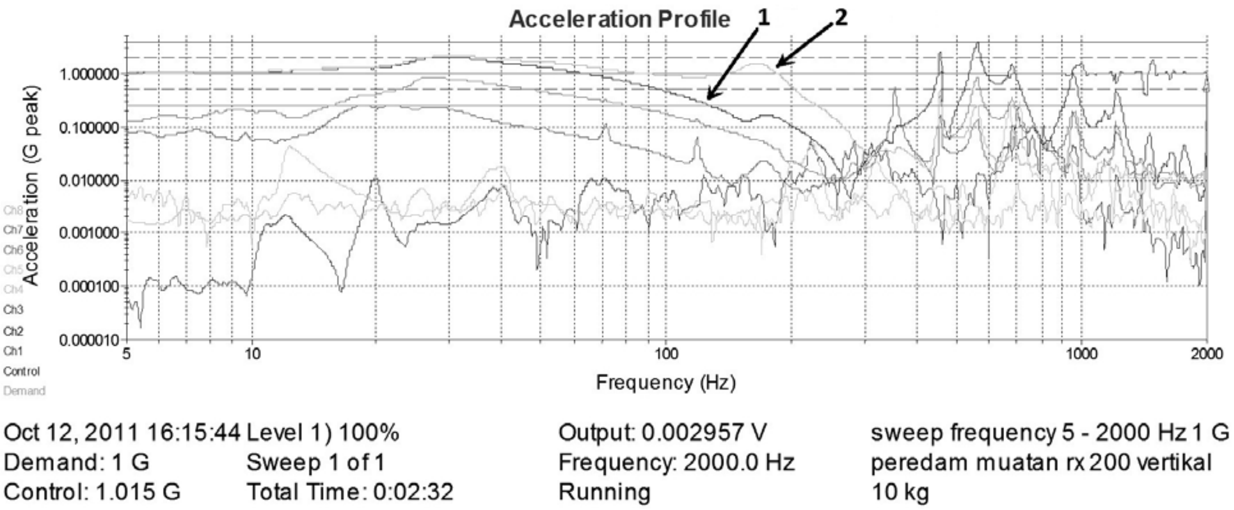

Figure 8. Amplitude vs. frequency curves for some testing points.

frequency-dan-putaran-kritis-critical-speed/
[6] Agus Harno et.al, “On-Board Fundamental Frequency Estimation of Rocket Flight Experiments Using DSP Microcontroller and Accelerometer,” *Jurnal Nasional Dirgantara*, 2009.
[7] T. Srinivas Reddy et.al, “Design and analysis of vibration test bed fixtures for space launch vehicles,” *Indian Journal of Science and Technology*, Vol. 3 No. 5, May 2010.
[8] Donghyun Hwang et.al, “Vibration Reduction module with Flexure Springs for Personal Tools,” World Academy of Science, Engineering and Technology 56, 2009.
[9] Holter Warren G, “Vibration reduction for electric motors,” US patent 07/985,097, 1997.
[10] Shin, Sang-chul, “Hard disk drive comprising flexible printed circuit with damping material," US patent 10/288507, 2002.
[11] LAPAN, Laporan Tahunan Bidang Kendali 2009.
[12] Advanced Vibration Components. (2012, November 14). *Technical Section: Vibration and Shock Isolation*. [Online]. Available: www.vibrationmounts.com
[13] Enidine. (2012, November 14). *Wire Rope Isolator Catalog*. [Online]. Available: www.enidine.com