Research Amplitudo Vibration On Holder Due To The Process Of Lathe Nozzle Rocket Rx 450

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Abstract. The main function of the rocket nozzle is to convert the enthalpy efficiency from combustion gas to kinetic energy and also to make high velocity out of the gas. The rocket nozzle usually consists of a converging and diverging part. With a smaller area on the neck and enlarged at the exit area. The velocity flow through the nozzle enlarges into the speed of sound through the neck and then becomes super sonic in the divergent part. Nozzle making or machining using conventional lathes, first performed is drilling on a massive metal that is bonded to the veneer, then after a sufficient gap is done deep-boring. At the time of the process of lathe in the nozzle RX 450 there is an obstacle that is vibrating tool holder chisel or holder so it is worried about not precision of the process of lathe. This should not happen because it can cause failure in the latter for it needs to be studied and studied further so that the lathe process goes accordingly.

The holder material of ST 60 with a modulus of elasticity 200 GPa and a nozzle material of AISI 4340 alloy steel with \(\sigma_{\text{yield}} = 470 \text{ MPa}\), Shear Modulus \(G = 80 \text{ GPa}\).

The purpose of this research is to observe the amplitude of vibration on the holder due to RX-450 nozzle lathe processing for the purpose of amplitude that occurs in accordance with the desired so that the nozzle structure is no damage process.

The result of the research was obtained holder with length (L) 80cm, profile width (B) 5 cm, height of profile (H) 10 cm, turning machine \(\omega = 8.98 \text{ rad / sec}\) and natural holder frequency \(\omega_n = 89.8 \text{ rad / second}\), Amplitude of vibration of \(\delta = 1.21 \text{ mm}\), while the amplitude of the design \(X = 1.22 \text{ mm}\)

From the results of this study it can be said that the holder of a chisel or holder can be used as a tool at the time of RX nozzle retrieval process and is quite safe because it works under the condition \(\omega/\omega_n <0.3\) (Plans and Specifications of A Suborbital Rocket Payload "AKPV Engineering University of Wyoming 2009")

1. Introduction

The main function of the rocket nozzle is to convert the enthalpy efficiency of the combustion gas to kinetic energy and also to make high exit speeds of the gas. The nozzle is a very efficient tool for gas acceleration to supersonic speed. The rocket nozzle usually consists of a converging and diverging part. With a smaller area on the neck and enlarged in the exit area. The velocity flow through the nozzle enlarges into the speed of sound through the neck and then becomes supersonic on the divergent part.

[3]

The pressure occurring in a rocket motor is channeled through the nozzle, giving rise to a thrust force coming out of the rocket nozzle. For that required precision in making the nozzle so that the maximum results obtained from the rocket.
Making or machining nozzles using conventional lathe. The first performed is a drilling on a massive round metal that is bonded to the veneer, then after getting a sufficient gap to be done deep-boring. In the deep-lathe process to create a nozzle embossed force that causes vibration in the holder. Vibration on the chisel can cause damage to the inner surface of the nozzle. For that need to be studied further so that the holder of a chisel or holder does not vibrate during the nozzle turner.[1,2,6]

The machining process of the lathe is the occurrence of relative motion between the chisel and the workpiece will result in the variation of the chip resulting in a change in force, so that the vibration amplitude continues to expand rapidly. Enlarged amplitude will create a high-pitched sound coming from the chisel that cuts off the workpiece. Increased amplitude is also caused because the energy used cutting will be absorbed by the system. The energy that excites the vibration comes from the cutting process itself is called self-excitation vibration or better known as the chatter. Chatter is the vibration that occurs when the chisel moves toward the workpiece on the cutting process. Chatter should be avoided as it can degrade surface quality even resulting in geometry errors. The causes of chatter vary, one of which is the cutting parameter. [9,12]

The purpose of this study is to observe the amplitude of vibration in the holder due to the RX-450 nozzle retention process which is aimed to amplitude that occurs in accordance with the desired so that the process of making nozzle structure no damage.

2. THEORETICAL BASIS
2.1. Force of lathe
To find out the phenomenon that occurs at the time of the nozzle, it is necessary to find the size of the lathing force that is:

Material nozzle structure made of stainless steel AISI 4340 with the following specifications:

\[ \sigma_y = 470 \text{ MPa}, \text{ Shear Modulus } G = 80 \text{ GPa}, \]

![Figure 1. Rocket Nozzle](image-url)
Figure 2. Schematic of lathes for forming rocket nozzle form

Figure 3. Total cutting force is resolved into two component, horizontal component vertical component

The relationship between furious with cutting force can be seen in the following formula [7]

\[ F = \tau_{sh} \cdot b \cdot h \cdot \frac{\cos(\eta - \gamma_\circ)}{\sin \phi \cos(\phi + \eta - \gamma_\circ)} \]  

Information:
F = Cutting force (N), \( \tau_{sh} \) = Shear stress in shear plane (N / mm²), b = cutting width (mm), h = Thickness before cutting (mm), \( \eta \) = Friction angle, \( \gamma_\circ \) = Angle growled, \( \phi \) = Shear angle
From the above formula can be seen that the resulting fury is directly proportional to the cutting force imposed on the workpiece.
The force generated from the cutting process by the chisel causes the chisel to vibrate. Vibration on the chisel will increase as the resulting cut style increases.[8]
2.2. Rigidity of the Cross Direction Column

Considered a holder structure with the tip of the tip and L length, given a force load of \( F \) at one end as shown above.

\[
F = \text{the lathing force, } L = \text{the length of the holder}
\]

The magnitude of the column stiffness of the holder structure is

\[
\delta = \frac{FL^3}{3EI}, \text{ and the rigidity of the column holder is } k = \frac{F}{\delta}, \text{ then}
\]

\[
k = \frac{3EI}{L^3} \quad [2.5]\]

Where:

\[
I = \frac{bh^3}{12} = \text{moment of profile inertia, } b = \text{column width, } h = \text{column height}
\]

\[
E = \text{Modulud elasticity of holder material} \quad [6]
\]

2.3. Natural Frequency

To obtain the natural frequency of the holder, the equation of motion of the holder system (see figure 5) is

\[
m\ddot{x} + c\dot{x} + kx = 0
\]

where the dampening system is ignored, the natural frequency is [1]:

\[
\omega_n = \sqrt{\frac{k}{m}} \quad [4]
\]

Where:

\[
k = \text{the column stiffness of the holder (N / m) and } m = \text{analogous as the lathe force (kg)}
\]

2.4. Vibration amplitude

To obtain the amplitude that occurs in the holder structure in the nozzle-bolting process, the following equations are used:

\[
X = \frac{F/k}{\sqrt{1 - (\omega/\omega_n)^2}} \quad [4]
\]

And the relationship between the amplitude ratio with the ratio of frequency to damping factor can be explained in figure 5 [4,5,11].
For structural strength as well as holder, the designed frequency ratio is $\omega / \omega_n < 0.3$, in order that the structure is not damaged due to large amplitude or resonance state. [11]

3. METHODOLOGY
The methodology used in designing the holder on RX 450 rocket nozzle was firstly searched for holder and nozzle data, large cut style, holder column elasticity modulus (ST 60), $\sigma_{\text{yield}}$ from nozzle material, and long holder (1) . And then calculate the stiffness of the column holder (k) to find the equation of motion, after which the natural frequencies of the holder structure and vibration amplitude are calculated.

4. DATA PROCESSING
4.1. Calculating cutting force on lathe
To calculate the magnitude of the cutting force in the lathe process, equations (1) Taken by cutting width (b) = 3 mm and the thickness of the flutter before cutting (h) = 2 mm 0.5 x 470
MPa = 235 MPa = 2.35 e2 N / mm², \( \eta - \gamma' = 35^0 \), \( \phi = 20^0 \) then the cutting force (F) is,

\[
F = 2.35 e2 \times 3 \times 2 \times \frac{\cos 35}{\sin 20 \times \cos 55} = 5887.68 \text{ N}
\]

With the help of a simple Microsoft Excel program, there is a large number of cutting force (F) with some cutting width (b) and thickness before cutting (h), can be seen in Table 1 below.

Where: \( \eta - \gamma' = 35^0 \), \( \phi = 20^0 \) dan \( \phi + \eta - \gamma' \)

| \( \tau_{sh} \) (N/mm²) | b (mm) | h (mm) | \( \cos(\eta - \gamma') \) | \( \cos(\phi + \eta - \gamma') \) | \( \sin \phi \) | F (N) |
|------------------|--------|--------|----------------|----------------|--------|--------|
| 2.35E+02         | 3      | 2      | 7.66E-01       | 0.50045969     | 0.341  | 5887.68|
| 2.35E+02         | 4      | 2      | 7.66E-01       | 0.50045969     | 0.341  | 7850.24|
| 2.35E+02         | 5      | 2      | 7.66E-01       | 0.50045969     | 0.341  | 9812.80|
| 2.35E+02         | 6      | 2      | 7.66E-01       | 0.50045969     | 0.341  | 11775.36|

4.2. Calculates column rigidity

\[
I = \text{moment of profile inertia} \quad I = \left( B H^3 / 12 \right) [10], \text{ where:}
\]

B = width of holder profile, H = height of holder profile E = Modulud elasticity holder (st 60 steel = 200 GPa), then the stiffness of the base cross direction column \( k_1 \) with \( L = 80 \text{ cm} \) is:

\[
k = \frac{3 EI}{L^3} \text{. Then } k = \frac{3 \times 200 \times 9 \times 9 - 7}{0.8^3} = 10.6 e 6 \text{ N / m}
\]

From the calculation of the cutting force of \( F = 5887.68 \text{ N} \), anf \( F = 5935 \text{ N} \) approach is taken as the calculation data for completion in the design of the holder.
4.3. Deflection of observation results and Calculate the vibration amplitude in the holder

Figure 8. Observing the vibration amplitude of the holder in the LAPAN structure laboratory

The result of observation at the time of RX 450 nozzle lathe was obtained for observation with condition

\[ \begin{align*}
B &= 0.06 \text{ m} \\
H &= 0.12 \text{ m} \\
L &= 0.8 \text{ m} \\
k &= 10 \times 10^6 \text{ N/m}^2
\end{align*} \]

Obtained deflection on measuring instrument \( \delta = 1.21 \times 10^{-3} \text{ m} \) and deflection by the calculation method obtained:

In this plan the holder structure is planned to work in the area of frequence ratio (see figure 5) and the attenuation factor is ignored or, then the above 3 equation becomes:

\[ X = \frac{F / k}{\sqrt{1 - (0.1)^2}} \].

Then

\[ X = \frac{5995 \times 10^6}{\sqrt{1 - (0.1)^2}} = 0.00122 \text{ m} \]

he design result obtained by the value of vibration amplitude \( X \), not too far with deflection \( \delta \) result of observation that happened, with difference of error value equal to

\[ \Delta = \frac{0.00059 - 0.00058}{0.00059} \times 100\% = 1\% . \]

And the above calculation and observation results with several holder profile sizes, length holder \( L = 0.8 \text{ m} \), and Modulus of elasticity \( E = 200 \text{ GPa} \), can be seen in table 2 below.

| F (N) | B (m) | H (m) | I (m^4) | K (N/m) | \( \omega \) (rad/DET) | \( \delta \) (m) | n (rpm) | X (m) |
|-------|-------|-------|---------|---------|-----------------|---------|--------|-------|
| 5935  | 0.03  | 0.06  | 5E-07   | 632812  | 32.341          | 9.38E-03| 31.6   | 0.00947 |
| 5935  | 0.04  | 0.08  | 2E-06   | 2000000 | 5.75            | 2.97E-03| 56.18  | 0.00299 |
| 5935  | 0.05  | 0.1   | 4E-06   | 4882813 | 8.98            | 1.21E-03| 87.77  | 0.00122 |
| 5935  | 0.06  | 0.12  | 9E-06   | 10e6    | 12.93           | 5.86E-04| 126.38 | 0.00059 |
\[ \delta = \text{Deflection of observations} \]
\[ X = \text{amplitude calculated} \]

5. RESULTS AND DISCUSSION

![Cutting Force VS Width Cutting](image_url)

**Figure 9.** The relationship between the cutting force against cutting width

Figure 9: Describes the relationship between the cutting width (b) to the cutting force F (N) on the RX 450 nozzle making. The larger cutting width is also the required cutting force. In this design nozzle material of AISI 4340 alloy steel with \( \sigma_{\text{yield}} = 470 \text{ MPa} \), Slide Modulus \( G = 80 \text{ GPa} \), cutting width \( b = 3 \text{ s/ d 6 mm} \) while 2 mm thick bolt, where \( \tau_{\text{shi}} = \text{Shear stress in shear plane (N / Mm2)} \) \( \tau_{\text{shi}} = \frac{1}{2} \sigma_{\text{yield}} = 2.35E + 02 \text{ N/mm}^2 \), friction angle \( \eta = 50^\circ \), shear angle \( \phi = 20^\circ \), and angle of angle \( \gamma = 15^\circ \), the design result by taking cutting width \( b = 3 \text{ mm} \) obtained by cutting force \( F = 5887.68 \text{ N} \).

In the design of RX 450 nozzle lathe, 3 mm width cut data and 2 mm thickness of bolster are required because the smallest cutting force is required to maintain the stability of the lathe during the cutting process. (See the design result in table 1) In the design of RX 450 nozzle lathe, 3 mm width cut data and 2 mm thickness of bolster are required because the smallest cutting force is required to maintain the stability of the lathe during the cutting process. (See the design result in table 1) [1,2,8,12]
**Figure 10.** The relationship between the moment of profile inertia against deflection and amplitude

Figure 10: Describes the deflection and amplitude occurring in the holder of the chisel lathe, it is seen that the greater the moment of profile inertia of the holder the smaller the deflection and amplitude occur. The deflection and amplitude are almost the same because at the time of designing the vibration amplitude is taken condition $\omega / \omega_n = 0.1$.

Results of holder sculpture holder design in RX 450 rocket nozzle processing with holder profile size as follows, width (B) = 0.06 m, height (H) = 0.12 m and length L = 0.8 m, with steel material ST 60 which has $E = 200$ GPa and cutting force of $F = 5587$ N, obtained a deflection on the holder of $X = 0.00122$ m and the result of observation $\delta = 1.21E-03$ m.

In the planning of vibration amplitude, the holder structure is planned to work in the area of the frequency ratio and the damping factor is negligible or, with $K = 10.6E6$ N/m, the vibration amplitude $X = 0.00122$ m is obtained.

The design result obtained by the value of vibration amplitude (X), not too far with deflection ($\delta$) result of research or observation with difference of value equal to $\Delta = 1%$.

From the moment graph of the profile inertia moment of the holder to the deflection and deflection (graph 2) seen the two graphs of deflection and amplitude coincide for all values of moment of profile inertia, this shows that the holder structure design is very safe because the frequency ratio is $\omega / \omega_n < 0.3$ (see figure 5)[1,2,6,8,11]

Deflection = 1.21 mm and amplitude X = 1.22 mm, with the size of the holder specified above can be used for holder design for the manufacture of RX 450 LAPAN nozzle.
6. CONCLUSION

From the results of research and design of holder holder chisel on the process of making nozzle RX 450 LAPAN can be concluded as follows:

Because the nozzle making by using conventional lathe requires a high degree of stability of the lathe tool, hence based on the result of the study selected holder with ST 60 material where the profile width (B) = 5 cm, height profile (H) = 10 cm and length L = 80 cm with a frequency ratio \( \omega/\omega_n = 0.1 \) with a rotational speed of 87.77 rpm, resulting in a vibration amplitude of 0.58 mm, quite safe because in addition to small amplitudes, the cutting process works on a fairly safe area that is in the frequency ratio \( \omega/\omega_n < 0.3 \) (recommendation from AKPV Engineering University of Wyoming).

The design result of RX 450 nozzle making process or with AISI 4340 alloy steel with \( \sigma_{\text{yield}} = 470 \) MPa required cutting force of \( F = 5935 \) N.

The observed amplitude on the holder due to the cutting force of \( \delta = 1.21 \) mm, the value is almost the same as the amplitude of design is \( X = 1.22 \) mm with deviation of \( \Delta = 1\% \). [8,9,11,12].

From the results of research can be said that the design of the holder in accordance with the planned and holder can be used as a tool holders chisel on the process of making the RX 450 LAPAN nozzle and can reduce vibration due to amplitude and deflection that occur in safe area for the strength of the holder structure.

The holder has been used on the lathe for the process of making the RX 450 LAPAN nozzle with satisfactory results.

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PHOTO TESTING

Figure 11 : observing the vibration amplitude of the holder in the LAPAN structure laboratory