Analysis on the operation condition of Rubber belt CVT of baja Racing car

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Abstract. baja racing is a kind of simple off-road racing originated in the United States, is the predecessor of Formula Student racing. This article through to the baja racing rubber belt type stepless transmission, for its mechanical characteristics, temperature characteristics and movement of the thermodynamic conditions of resonance are analyzed when the validation, thus more clearly the working characteristics of the rubber belt type stepless transmission to optimization design in after the game, make it can match various complex conditions of movement and maintain maximum speed ratio. This paper USES CATIA to establish the model, USES the MODAL module of ANSYS WORKBENCH to carry out the 12-order MODAL analysis, USES STATIC STRUCTURAL to carry out the force analysis, USES Steady State Thermal to carry out the analysis of the temperature change when the rubber belt stepless transmission works, and USES Matlab to carry out the simple automobile vibration simulation analysis. Finally, the conclusion is drawn and the design optimization analysis is carried out, so that the rubber belt CVT can achieve better dynamic performance and structural stability.

Keywords: baja racing, vibration analysis, modal analysis, steady-state thermal analysis, ANSYS, Matlab.

1. Introduction (Heading 1)
Baja’i Viet Nam Competition ("BSC") is an automobile design and production competition organized by college students with automotive engineering or automotive related branches. According to racing and racing production standards, each team has designed and built a small cross-country race car with excellent performance within one-year, medium engine and rear drive, and can successfully complete all or part of the race.

The school adopts baja racing car belt stepless transmission, low cost, simple structure, high design requirements, mainly used for motorcycle, off-road vehicle and sleigh vehicle transmission power. Almost all baja teams at home and abroad use this CVT, but it is difficult to meet the requirements of baja, which has the defects of poor power and low transmission efficiency. Foreign universities have
created a more mature technology system, such as the strong team of the University of baja, Michigan, for many years of technical research and accumulation, self-made CVT began to achieve better power and speed control performance, and the domestic is just beginning.[1]

The power matching, transmission efficiency and speed change performance of the native baja team are generally poor, and the lack of effective design solutions is an urgent need for more people to join the site and help to provide more exemplary and effective solutions.

2. Building CVT Models
The school uses a self-made CVT model, according to the 2018 China Institute of Automotive Engineering baja Competition rules, the CVT must use steel or aluminum plate, the use of steel must be at least in accordance with the Chinese steel standard 10# low carbon steel strength (AISI 1010),1.5 mm. thickness or use high strength aluminum, standard is:6061- T6, thickness minimum 3.0 mm. Baffles, shields must extend around the perimeter of the belt or chain, surround CVT entire perimeter pulley, and must be wider than the rotating parts they protect. These baffles must be properly installed to withstand the vibration of the car running and driving. [2]

3. Example Analysis
In 2019, the frame of Wuhan Polytechnic baja was partially overweight, which affected the speed limit. But thanks to the excellent transmission efficiency of the transmission system, it still has excellent transmission rate. At the same time, the reasonable layout of the CVT makes it not subject to severe external impact, and the Baja’s car does not cause internal damage because of excessive vibration when it passes through the rugged section. The high temperature of 80℃ will be produced in the process of CVT high speed operation, but after this analysis is improved, the CVT does not appear obvious deformation under the long-time high temperature work.

4. Finite Element Model Ansys Frame
The CATIA model is imported into the ANSYS WORKBENCH and different analysis of rubber belt CVT is carried out by opening different modules. This analysis will consider the reality, rubber belt stepless transmission will adopt aluminum alloy material.

Set the correct parameters:

| Aluminium Gold Number and Status | 5052- H112 |
|----------------------------------|------------|
| Tensile strength (25℃) MPa      | 175        |
| Yield strength (25℃) MPa        | 195        |
| hardness 50 kg force 10 mm ball | 60         |
| Extensibility 1.6 mm (1/16in) thickness | 12 |

5. CVT Statics Analysis
5.1. CVT deformation bending
In the course of the baja race, the car will have a certain chance of impact because of the need to pass the rugged road. As the position of the impact appears in the rear, the CVT will be deformed by the impact. By optimizing the design of the frame of baja racing car to change the angle of CVT bearing force, it can be seen that the performance of the whole vehicle has been greatly improved. From ANSYS analysis, we can see:

Load:
1. Fixed the driven shaft connecting wheel of CVT and loaded 700 N impact force on both sides of the driven wheel.
2. Increase the acceleration g of a parallel horizontal vertical driven wheel on the side (g).
3. Load the binding 850 N between CVT and baja car steel tube frame to simulate the installation process. g. of gravity acceleration

4. Loading $g = 9.8m/s^2$

Constraints:
1. constraint CVT the Z axis movement direction of the connecting key points.
2. Constraint follower Z shaft movement, in order to simulate the stability of the frame, the default frame is within the specified deformation.
3. Restrain all the freedom of the belt to ensure the normal operation of the belt.

Analysis:
By ANSYS analysis, we can see that the rubber belt stepless transmission has the greatest force at the active pulley and the follower pulley, which produces a certain degree of deformation. The steel pipe at the end of the baja car can be used as the main steel requirement. In this way, the stability of the rear of the baja car can be enhanced under the condition of increasing the weight of the whole car, so that the whole car has better safety performance.

6. 12 Modal Analysis

6.1. ANSYS Modal Module analysis
The Baja’s racecourse is very rugged off-road terrain, so there will be violent vibration. By ANSYS the modal analysis of the software to improve the structure, the vibration characteristic frequency of the baja car during the driving of the rugged section is obtained, and the main variable characteristics are found. In order to improve the structure of baja car steel tube frame, and then make the rubber belt stepless transmission maintain stability under severe vibration.

Modal analysis is to study the inherent dynamic characteristics of the object itself: frequency, damping and mode, etc., through which the main characteristics of the structure are represented. Because the first six modes of modal analysis belong to rigid mode, the whole 12th order mode is selected for analysis.

According to the matrix iteration method, the system motion equation can be expressed as

$$\omega_n^2 \{A\} = [M]^{-1}[K]\{A\}$$

Instead of the stiffness matrix, the equation of motion can be rewritten to:

$$\frac{1}{\omega_n^2} \{A\} = [R][M]\{A\}$$

The following iteration is followed:

$$[R][M]\{A\}_i = \frac{1}{\omega_n^2}\{A\}_{i+1}$$

After several steps, if any

$$\{A\}_i = \{A\}_i$$

$$\{A\}_{i+1}$$ Then the main mode. Otherwise, continue the iterative calculation according to the above formula. When the first order mode is obtained, the matrix iterative algorithm can be used to calculate the inherent frequency and the main mode of each order one by one.

In the finite element analysis, the model characteristics of continuous vibration system can be solved. The outstanding advantage of finite element is generality, which can solve the natural frequency and mode of any elastic system.

The general method of finite element is:

$$l \xi : 0 \leq \xi \leq l u(\xi, t)$$ To represent the length of the unit and define the local coordinates. The displacement of the element is made and the continuity condition is satisfied. If the unit degree of freedom is represented, then: $u_1, u_2, ..., u_k$
\[ u(\xi, t) = \sum_{i=1}^{k} \phi(\xi)u(t) \]

\[ \phi(\xi) \] Where, \( \phi \) is the shape function. The expression of potential energy and kinetic energy of the element can be obtained from the displacement and the upper formula, and its secondary forms are as follows:

\[ V = \frac{1}{2} u^T ku \]
\[ T = \frac{1}{2} (u :)^T m(u : ) \]

The \( k \) is stiffness proof and the \( m \) is mass matrix. According to the conservation of energy theorem, the equations of motion of the system can be written as:

\[ M(U : ) + Ku = 0 \]

According to the ANSYS analysis, we can obtain the twelve-order modal analysis of the rubber belt CVT, as shown in Table 2:

| Mode | Frequency [Hz] |
|------|----------------|
| 1    | 0              |
| 2    | 0              |
| 3    | 0              |
| 4    | 0              |
| 5    | 0              |
| 6    | 0              |
| 7    | 0              |
| 8    | 2.0324e-003   |
| 9    | 2.8802e-003   |
| 10   | 3.5536e-003   |
| 11   | 5.6158e-003   |
| 12   | 8.2267e-003   |

There are two main external incentives for the Baja’s car to travel along rough roads:
1. a variety of complex road uneven excitation transfer to the body, the axle will vibrate, the whole terrain of the body suspension system part of the mass deviation of about 2-3 Hz, crack mass deviation of about 20 Hz, there will be no resonance phenomenon.

generate internal engine vibration 2. different working states. However, with deceleration, normal operation, acceleration and other running wheels, the deceleration (speed) of other running wheels after deceleration may slow down.

Engine excitation frequency = (2* engine frequency * engine rotation)/ (engine stroke number 60)

A choice place for the car is the Bailitong M20 cylinder 4 administrative air-cooled engines. This resonance rate is in the range of the highest rotation speed of 2000–3600 r/min. The vibration frequency ranges from 17.71 to 30 Hz. ~ calculated This frequency is lower than the natural frequency of the body, so there will be no resonance."3".

7. Matlab Module Analysis
The vehicle will produce a certain degree of vibration in the process of driving, in which the vibration will produce exciting effect on each component. to verify the practical effect of this effect, it can be analyzed by Matlab establishing a simple vibration model. As shown in figure 1, figure 1 is a simple resonant diagram of a single degree of freedom system.
The vibration differential equation of a single-degree-of-freedom vibration system of an automobile is established as:

\[ f(t) = F_0 \sin \omega t \]

\[ m(x'') + c(x') + kx = F_0 \sin \omega t \]

Its input into the MATLAB running code is:

\[
\begin{align*}
\text{s} &= [0.1 \text{ per cent } 0.15 0.25 0.5] \\
\text{B} &= []; \\
\text{p} &= []; \\
\text{for} \ i &= 1:4 \\
\text{for} \ j &= 1:301 \\
\text{r} &= (0.01:3); \text{B} (j) &= 1/ \sqrt{1 - r(j)^2}(2* \text{s (i)}* r(j))^2; \%	ext{ represent amplification factor } \beta \\
\text{p} (j) &= \pi - p(j); \\
\text{if} \ r(j) > 1 \\
\text{p} (j) &= \pi - p(j); \\
\text{end} \\
\text{end} \\
\text{subplot}(1,2,1); \\
\text{if} \ i &= 1 \\
\text{plot} (r, \text{B},'-') \\
\text{elseif} \ i &= 2 \\
\text{plot} (r, \text{B},'--') \\
\text{elseif} \ i &= 3 \\
\text{plot} (r, \text{B},':') \\
\text{else} \\
\text{plot} (r, \text{B},'-.') \\
\text{end} \\
\text{legend} ('s=0.1','s=0.15','s=0.25','s=0.5') \\
\text{grid on;} \\
\text{xlabel(' frequency ratio')} \\
\text{ylabel(' amplification factor')} \\
\text{title(' amplitude-frequency characteristics')} \\
\text{hold on;} \\
\text{subplot}(1,2,2) \\
\text{if} \ i &= 1 \\
\text{plot} (r, \text{p},'--') \\
\end{align*}
\]

Figure 1. Simple resonant vibration of single degree of freedom system
elseif \( i == 2 \)
plot (r, p, ‘--’)
elseif \( i == 3 \)
plot (r, p, ‘:’)
else
plot (r, p, ‘-.’)
end
grid on;
xlabel(' frequency ratio')
ylabel(' phase angle')
title(' Phase Frequency Characteristics')
hold on;
end

The output is shown in Figure 2 and Figure 3:

![Figure 2. The Output](image)

![Figure 3. The output images](image)

8. Thermodynamic Analysis of Rubber Belt Continuously Variable Transmission

The baja car will produce a lot of heat under the condition of high-speed operation, and the rubber belt continuously variable transmission will produce greater performance pressure on itself because of its complex working conditions and rapid direction change. Normal CVT will reach 40–50°C temperature, but baja racing CVT temperature will reach 60°C. In this case, it is very important to understand the working situation of baja racing CVT at high temperature. For ensuring the normal operation and the
high efficiency of the performance, it is necessary not only to optimize the design of the CVT shell, but also to add more hollowed-out treatment so as to protect it from the external force and ensure the normal heat dissipation function of the CVT. According to the actual verification, the shell of CVT can be spliced with aluminum plate, and the mechanical performance after punching and hollowing has not obviously decreased with the impact resistance of the original model. But the heat dissipation function of CVT has been greatly improved. At the same time, the size and density of the control hole will also reduce the weight of the car and keep the flying stone from entering.

By means of fluid mechanics and thermodynamic analysis, Newton's basic formula for calculating convection heat transfer is

\[
\Phi = Ah(t_w - t_f)
\]

\[
q = h(t_w - t_f)
\]

t_w, t_f The formula is: solid wall temperature, °C; fluid temperature, °C. h called convection heat transfer coefficient, commonly known as convection heat transfer coefficient, the unit is:

\[
W / (m^2 \cdot K)
\]

The thermal conductivity of aluminum is 237 in the ANSYS Steady-State W/mK, Considering the environment of the competition, the base temperature can be set to 35°C, and five order states can be set in the analysis setting to ensure the diverse accuracy of the test. By heating the conveyor belt, the active wheel and the driven wheel hub, the heat flux is added to the riveting,. Finally, the heat flux is loaded on the inner side of the conveyor belt. 45W / m²

After thermodynamic analysis, the temperature distribution zone is obtained, as shown in figure 4 and Table 3.

**Figure 4. Temperature change chart**

**Table 3. Temperature Change Table**

| Time[s] | Minimum (°C) | Maximum (°C) |
|---------|--------------|--------------|
| 1       | 54.365       | 84.08        |
| 2       | 54.365       | 84.08        |
| 3       | 54.365       | 84.08        |
| 4       | 54.365       | 84.08        |
| 5       | 54.365       | 84.08        |

The minimum total temperature flow is 2005W/m³ and maximum change of total temperature flow is 293822W/m³.

The heat flow meter measures X, Y, and Z is 21.421W/m², 113.25W/m², 723.77W/m².

After the whole verification, it is proved that the rubber belt stepless transmission of baja car meets the design requirements of working conditions. It can maintain good working performance and good stress conditions when baja racing passes through various complex terrain. The design is verified by competition.
9. Analysis Summary
Through the design analysis and verification, the structure of the frame can be optimized to a certain extent, which can make the performance of the whole vehicle highly optimized. Through the static force analysis, it can be seen that the rubber belt stepless transmission of baja car can withstand enough impact under complex working conditions, thus improving the safety of the whole vehicle and improving the operating space of the players to obtain a better position. Through modal analysis, it can be verified that the rubber belt stepless transmission of baja car can still maintain a certain structural stability, meet the design requirements and working conditions when the whole vehicle is subjected to great vibration interference. The outer ring of the transmission is wrapped with perforated hollow aluminum shell, which not only meets the requirements of the competition, but also protects the CVT to a certain extent, reduces the weight of the whole vehicle and improves the heat dissipation ability of the CVT. Finally, in thermodynamic analysis, it can be found that when the whole vehicle produces large heat at high speed, the CVT still has better thermodynamic performance and can maintain the ability of high efficiency transfer force.

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