Profiling the cam of the centrifugal screwdown structure of the V-belt variator

Alexey Mamaev, Tatiana Balabina, Maria Karelina

1 Moscow Polytechnic University (Moscow Polytech), 107023 Moscow, Russian Federation
2 The Moscow Automobile And Road Construction State Technical University (MADI), 125319 Moscow Russian Federation

Abstract. We consider the problem of profiling the cam of centrifugal pressure device of the driving pulley of V-belt variator which parameters and, first of all, profile would allow to create the optimal axial forces corresponding to the required mode of the transmission operation. A methodology for determining the required optimum axial forces from the condition to ensure the best traction ability of the belt transmission is given.

1 Introduction

In a number of mechanical systems, e.g. vehicle transmissions, the transmission ratio has to vary according to the speed and force conditions. For example, V-belt variators are used for infinitely variable transmission ratio control. This ensures that the optimum automatic control of the transmission is realised in such a way that the combustion engine works at a constant output, the highest torque, or the lowest fuel consumption rate. In the V-belt variator, the automation of its control is achieved by using the dependence of the axial forces on the pulleys on the mode of operation. Theoretical and experimental studies of such mechanisms are reflected in various works, e.g. [1-7].

A centrifugal cam device (Fig. 1), in which the cam creates the axial force, can be used as a thrust device to generate the axial force on the pulleys of a V-belt variator. However, analytical profiling of the required cam profile is not available in the literature. This raises the challenge of designing a cam whose parameters, especially its profile, ensure that the axial forces required are optimal and in line with the operating mode of the transmission.

2 Theoretical part

To obtain a cam profile that corresponds to optimum axial thrust $F_x$, consider the fact that for each position of the pressure plate (Fig. 2), determined by the amount of its movement $x$, corresponds to a certain force $F_x = f(x)$, and each movement of the disc $x$, equal to the axial movement of the cam, corresponds to a certain angle $\alpha$ of its rotation. In turn, the axial force developed by the centrifugal force on the cam also depends on the position of the

* Corresponding author: mamist-man@rambler.ru

© The Authors, published by EDP Sciences. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (https://creativecommons.org/licenses/by/4.0/).
Thus, it is possible to obtain the following relationship
\[ \alpha = f(x; F_x) \]

The cam angle from its axial movement with known axial force \( F_x \).

When profiling the cam we apply the motion reversal method - we mentally stop the cam by giving the entire cam mechanism an additional angular velocity \( -\omega_k \) and linear velocity \( -v_k \), equal in magnitude and opposite in direction to, respectively, the angular \( \omega_k \) and linear \( v_k \) to the speed of the cam (fig. 2). As a result, the pusher with the centre \( O_2 \) will rotate around the centre of the cam with an angular velocity of \( -\omega_k \), having a linear velocity \( -v_k \).

Each rotation angle \( \alpha \) of the tappet axis will correspond to a certain displacement \( x \) of the tappet along its axis.

Fig. 1. 1 - cam, 2 - belt, 3 - pulleys.

Fig. 2. Forces acting on the cam.

\[ \ell = \sqrt{e^2 + (X + x)^2} \]

(1)

\[ \sum A_{F_c} = \sum A_{F_n} \]

(2)

\[ rF_c \sin(\alpha_0 + \alpha) d\alpha = F_x d_x \]

or

\[ \int_{\alpha=0}^{\alpha} rF_c \sin(\alpha_0 + \alpha) d\alpha = \int_{x=0}^{x} F_x d_x \]

(3)

(4)

\[ F_c \]
\[ m \Omega^2 r [R \cos \alpha_0 - R \cos (\alpha_0 + \alpha) - \frac{r}{2} \cos^2 \alpha_0 + \frac{r}{2} \cos^2 (\alpha_0 + \alpha)] = \int_{x=0}^{x} F_x \, dx \] (5)

\[ y_{1,2} = \frac{1}{r} \left[ R \pm \sqrt{(R - r \cos \alpha_0)^2 + \frac{2}{m \Omega^2} \int_{x=0}^{x} F_x \, dx} \right], \] (6)

\[ \alpha = \arccos \left\{ \frac{1}{r} \left[ R - \sqrt{(R - r \cos \alpha_0)^2 + \frac{2}{m \Omega^2} \int_{x=0}^{x} F_x \, dx} \right] \right\} - \alpha_0. \] (7)

\[ \int_{x=0}^{x} F_x \, dx = \sum_{i=0}^{n} \frac{\Delta x}{2} \left( F_{x_i} + F_{x_{i+1}} \right), \] (8)

\[ l_i = \sqrt{e^2 + (X + x_i)^2} \] (9)

\[ \alpha_i = \arccos \left\{ \frac{1}{r} \left[ R - \sqrt{(R - r \cos \alpha_0)^2 + \frac{2}{m \Omega^2} \sum_{i=0}^{n} \left( F_{x_i} + F_{x_{i+1}} \right)} \right] \right\} - \alpha_0. \] (10)

\[ P_p(\Omega) + \mu T_p(\Omega) = \max, \] (11)

\[ \mu_1 \leq \mu \leq \mu_2, \] where \( \mu_1 = \frac{P}{T} \) and \( \mu_2 = \frac{P_{\max}}{T} \),

\[ \Omega = \Omega_1 \leq \Omega_A < \Omega_2. \]
Selection of optimum speed

Thus, with a known optimum force $F_{x_i}$ appropriate to a certain position $x_i$ of the pressure plate, by (10) and (9) it is possible to find the rotation angle $\alpha_i$ and the radius is a vector $\ell_i$, defining the cam centre profile.

3 Calculations

Following the recommendations of B.A. Pronin and G.A. Revkov [1], the sequence of calculations for the case in question is given below. We will assume that the smallest diameter has already been selected $d_1$ drive pulley, largest diameter $D_2$ the driven pulley, the regulation range is known, the belt length is selected and the cross-sectional dimensions of the belt are known.

1. Set the optimum torque value $T_1$ on the drive sheave.

2. Determine the current design diameter of the drive pulley $d_{x1i} = d_1 + x_{1i} \tan \varphi / 2$\(, \quad (12)\)

3. Determine the circumferential force on the drive sheave $F_t = 2T_1 / d_{x1i}$\(, \quad (13)\)

4. Set the average value of the optimum value of the traction coefficient $\psi = 0.675$.

5. Determine the value of $m = (1 + \psi) / (1 - \psi)$\(.

6. Find the relative axial force on the drive pulley $F_{x dp} / F_t = Y_{dp} = \cos(\varphi_2 / 2) + m (\theta_n / 2tg (\rho + \varphi / 2))$, \(\quad (14)\)
7. Determine the required axial force on the traction sheave
\[ F_{x_{dp}} = Y_{dp} F_t. \] (15)

8. Find the optimum axial force developed by each of the drive sheave cams,
\[ F_{x_i} = \frac{1}{z} (F_{x_{dp}} + F_{sp}). \] (16)

After determining the axial force at the initial position of the traction sheave, find \( F_{x_1} \) by \( x_1 \), \( F_{x_2} \) by \( x_2 \), and etc.

Since motor vehicles are regulated by both engine crankshaft speed and drag torque, in this case it is necessary to find the axial force \( F_{x_{rm}} \) on the idler pulley as a function of torque \( T_2 \) and slave disc movement \( x_{rm} \), which is used to select the characteristic and type of pressure device for the driven pulley.

Sequence of subsequent axial force determination \( F_{x_{rm}} \) and its corresponding torque \( T_2 \) on the idler pulley will be as follows:

1. Determining the current estimated diameter of the driven pulley
\[ d_{x_2} = \sqrt{(\pi a - d_{x_1})^2 + 4a(L - 2a) - (2\pi a - d_{x_1})d_{x_1} - \pi(a - d_{x_1})}, \] (17)

2. Determination of idler pulley displacement
\[ x_{z_2} = (D - d_{x_2})\tan(\frac{\varphi}{2}). \] (18)

3. Determining the relative axial force of the driven pulley
\[ F_{x_{rm}} = Y_{rm} = \frac{1}{2f_z \tan(\rho_2 + \frac{\varphi}{2})} + \frac{1}{m-1 \tan(\rho + \frac{\varphi}{2})}. \] (19)

4. Determining the required axial force on the idler pulley
\[ F_{x_{rm}} = Y_{rm} F_t. \] (20)

5. Determining the resisting torque to be overcome
\[ T_2 = F_t d_{x_2}/2. \] (21)
Based on this relationship 

\[ F_{x_{r}} = f(x_{r}; T_2) \]

4 Conclusion

In the presented work the problem of designing the cam of centrifugal pushing device of pulley of stepless V-belt transmission (variator) which profile allows to create optimal axial forces corresponding to the required mode of transmission operation is solved. Methodology is given to determine the optimum axial forces required from the condition to provide the best traction ability of the belt transmission.

References

5. N.M. Phil'kin, S.A. Shvetsov, Advances in modern mechanical engineering 4, 140-142 (2008)
7. M.B. Nabiyev, Universum: technical sciences: electronic scientific journal 10(103), 2022

https://doi.org/10.1051/e3sconf/202340210017