EXAMINATION OF DRIVE MISALIGNMENT AFFECTING THE POWER LOSS OF V-BELT DRIVES

Dr. László Kátai, Dr. Péter Szendrő, Péter Gárdonyi and Dr. István Szabó*

ABSTRACT

The V-belt drive heats up during power transmission, i.e. a significant part of power loss turns into heat and is transferred to the environment. The efficiency of V-belt drives is determined by several factors collectively: the slip occurring during drive transmission, the external friction occurring when the belt enters and exits the pulley as well as the hysteresis loss resulting from inner friction.

Main objective of this paper is analyzing the temperature conditions of V-belt by infrared thermal camera depending on various belt pulley parallel and angle misalignment. A certain V-belt cross section was analyzed on a self developed test equipment in various belt pulley parallel and angle misalignment. It was stated that the temperature increase of V-belt is influenced by the geometrical misalignment. In this study an experimental method was developed to define the V-belt temperature increase in function of belt pulley parallel and angle misalignment.

On the bases of the test results optimal parameters can be calculated that serve as beneficial references for designing and tuning V-belt drives.

Keywords: V-belt, infrared thermal analysis, belt misalignment, temperature conditions, belt efficiency

1. Introduction

V-belt drives are widely used in various industrial and agricultural equipment for power transmission. Power transmission is based on friction which has some advantages and disadvantages. Since the drive element is made from flexible materials, the drive will be flexible and minor load peaks might occur. In case of overload the driven side is protected by slipping. However, friction also means that due to the slip the transmission (i.e. the revolution of the driven equipment) may vary between certain limits, and therefore it can only be used in such areas where this is not a disadvantage.

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*Faculty of Mechanical Engineering, Szent István University – Institute of Mechanics and Machinery,

E-mail address: katai.laszlo@gek.szie.hu

According to Gerbert [9] the power loss occurring with V-belt drive can be basically divided into two groups, the loss caused by external friction (slip between the belt and the pulley) as well as the loss caused by internal friction (slip among the molecules, hysteresis).

These losses may be further categorized and divided taking into account the operating characteristics of the drive. Another source of loss is the gradual slip that occurs during the operation of the drive. This may be classified as external friction, which is caused by belt creep resulting in the actual slip. The secondary source of loss – which may be classified as external friction – is the slip between the belt and the pulley surface when the belt enters and exits the pulley [1, 2, 4, 5, 17]. The phenomenon of slip and the effect of drive characteristics on slip is analysed by Gerbert [9] in detail.

Several researchers lay special emphasis on studying slip caused by belt creep. The friction and elasticity of the belt along the angle of wrap is a distinction that can be made between the angular domains of adhesion and slippage. This relative displacement occurs between the pulley and the belt, which also leads to heat generation [6, 8, 14, 16]. The loss occurring during the entry and exit phase was also studied by Gerbert [9], which shows a larger margin of loss.

The loss resulting from inner friction (hysteresis loss) occurs when the belt is bent on the pulley (bending loss), which undergoes elongation due to the force of the power transmission (loading loss) and is then compressed in the pulley groove (compression loss). The terms in brackets are used by Gervas and Pronin [11]. According to both Gerbert [9] and Gervas [12] the load loss is extremely small. On the basis of the studies by Gerbert, the parameters typical of the tests which were run showed that the loss resulting from compression was smaller by more than one order of magnitude than the bending loss, so its effects were ignored during our study.

The engagement of the V-belt and the pulley, the elemental slips (relative motions) are affected by several factors in addition to drive parameters, such as operating conditions, the polluted environment, temperature and relative humidity as well as drive alignment errors, etc. These macroscopic slips cause belt wear and the heat generated by friction affects the steady transfer of power and its efficiency. The friction has an important role as it was studied by Safranyik et. al. [15]. Moon and Wickert (1999) [13] studied the radial belt motions in the case of aligning parallel misaligned pulleys and their effect on the stage of belt engagement. Figure 1 presents enlarged images of the bucking, frictional motion of the V-belt in the groove due to misalignment errors.

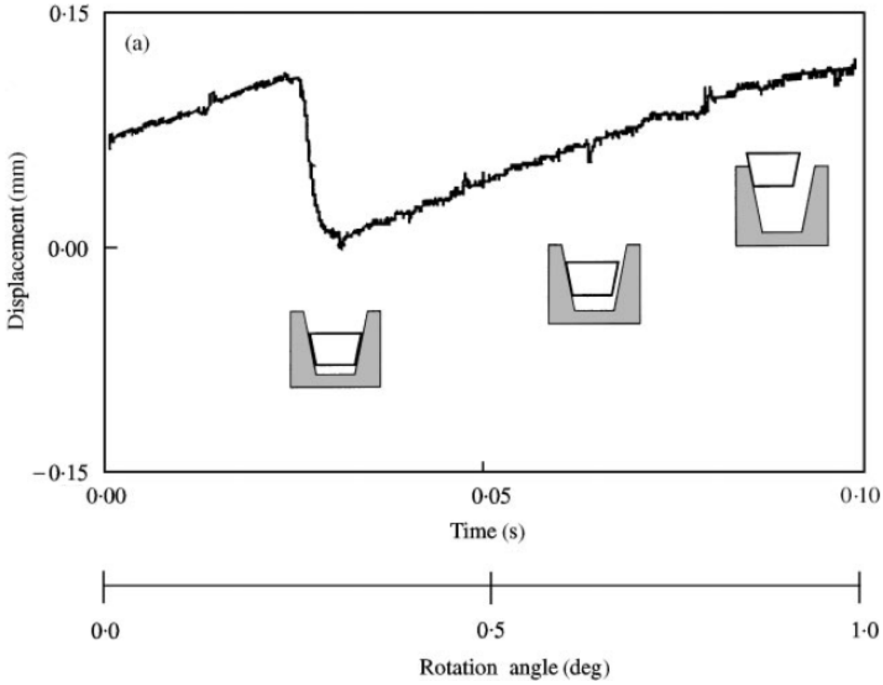

Figure 1: Stick-slip behaviour of V-belt in the groove

The maximum tolerances regarding V-belt drive alignment are given by the producers as a function of the pulley diameter. The nature of the occurring error is disregarded. The maximum tolerance may be due to the parallel misalignment of the pulleys (Figure 2/a) or the angular misalignment (Figure 2/b) too. In both cases the straight belt sections undergo extra bending and the sidewalls experience larger friction where running onto and off the pulley. In the case of parallel misalignment the friction increases on both sides, in the case of angular misalignment it is strained more on one side only. Here is the interpretation of a strained and an unstrained side. (Gárdonyi, 2014) [7]

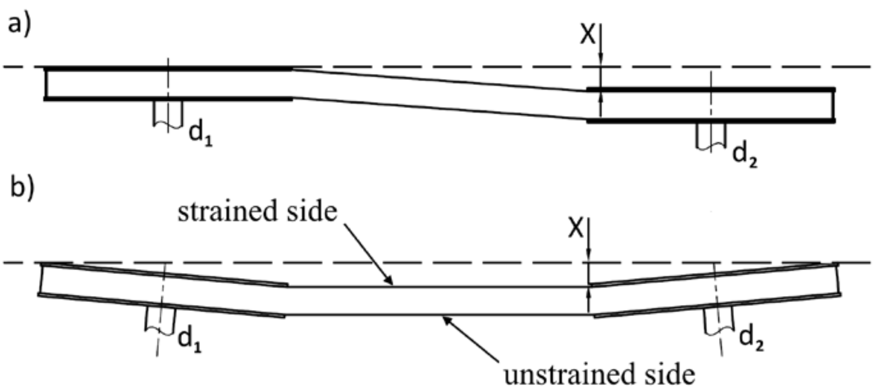

Figure 2: Explanation the adjustment errors of pulleys

a) parallel misalignment; b) angular misalignment

In this article on the one hand the loss in connection with factor κ , on the other hand the losses due to drive installation misalignment are analysed. The increase in temperature occurring as a result of bending combined with the belt entering and exiting the groove is investigated by developing an experimental method of calculation.

2. Material and method

The tests were performed on a universal test bench designed by PhD students doing research in the Department of Machine Construction. For the test procedure the drive unit was equipped with a tensioning unit guided by a linear bearing. The pretension of the belt can be adjusted with a screw spindle, whose line of action coincides with that of the shaft pulling force (F_H). This arrangement is used to measure the shaft pulling force directly. The universal test equipment structure can be seen in Figure 3. During the measurements all the driving parameters can be recorded through a measuring-data collecting unit furthermore to define these parameters with the help of a PLC device.

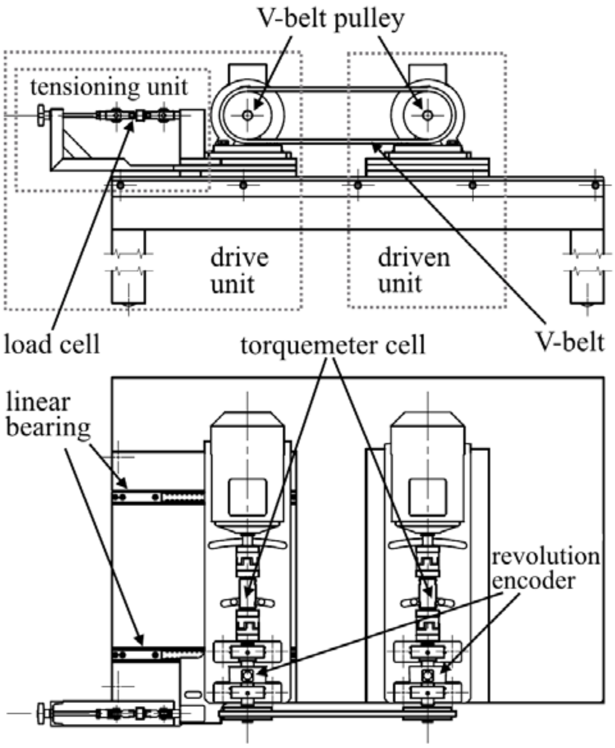

Figure 3: The structure of the test equipment

The temperature of the V-belt is determined by the equilibrium of the generated heat and heat loss. This is affected by several not easily controllable factors, such as air temperature, humidity, the temperature and heat capacity of the contacting parts, etc. During the experiments the mentioned not easily controllable factors were considered constant as the measurements were taken under the same circumstances. The temperature rise of the V-belt was chosen as the test parameter, which means the power loss between the two equilibria – between the steady state of the workshop temperature and operating temperature.

During our experiments the sidewalls of the belt coming in contact with the groove were tested, which contained more information about the operation of the drive. Data regarding the temperature were obtained from the thermal images taken of the active surface of the V-belt after the images were processed.

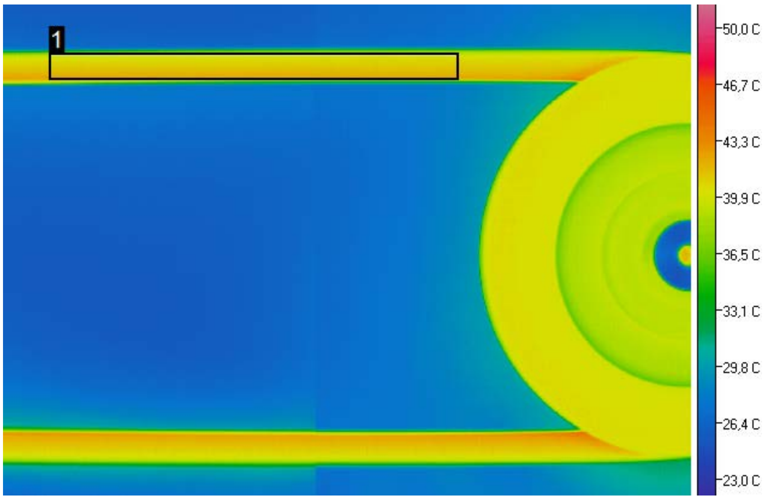

Figure 4: Thermal camera image and the sampling area

The average temperature of the marked area (1) (Fig. 4) in the tight side was used for the evaluation, which shows the temperature increase of the belt.

3. The results of the tests

First the experiments were conducted with SPA profile V-belts without load. Figure 5 shows that the relationship of the belt frequency and temperature increase is linear in the studied range, i.e. the frequency of the bending strain of the belt is directly proportional to warming.

However, it can be observed when running the V-belt drive that the lower side of the belt warms up more intensively than the upper side. This difference and the previously mentioned temperature increase occurring as a function of belt bending is caused by the so-called hysteresis loss due to repetitive strain. The neutral cord of the belt cross-section is situated nearer the top side, the lower cords are more subject to bending, therefore as a result of the inner friction more heat is generated going towards the lower side.

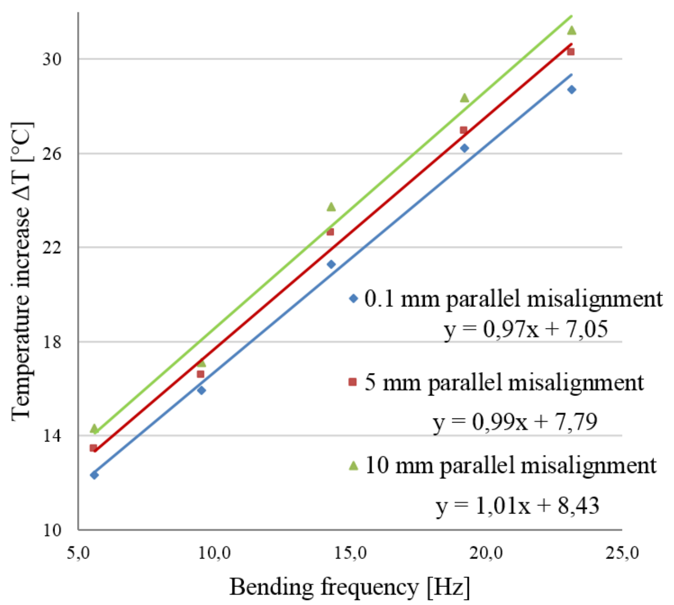

Figure 5: The heat generated as a consequence of the parallel misalignment of V-belt pulleys as a function of bending frequency

(SPA; d_1 = 112 mm; i = 1; L_d = 1207; f_0 =5,6 - 23,1 s^{-1}; M_1 = 0 Nm)

In the case of the parallel misalignment of pulleys, due to the adjustment error the V-belts reached the steady state at a higher temperature (Figure 5), i.e. they worked with higher loss. The parallel misalignment errors of the V-belt pulleys increased the temperature of the belt with a constant value independent of belt frequency, i.e. this excess heat does not come from the inner friction of the material of the V-belt. The heat load generated by the adjustment errors of the pulleys is caused by the changed friction conditions. The largest error set up during the experiments resulted in 10% temperature increase at each belt bending frequency.

In the other experiments SPZ V-belts were used, where the pulleys were set in the plane of the drive, at the recommended error limit, at a value one order of magnitude larger, and at double that value. The position of the pulleys relative to each other was created with parallel alignment and the angular alignment of the shafts.

Due to the adjustment errors of the pulleys the V-belt drives operate at a higher temperature, thereby the efficiency of the drive becomes worse and the service life of the V-belt decreases. Figure 6 shows that in addition to the extent of the adjustment error the temperature increase of the V-belt is also affected by the nature of the error. The angular misalignment of the pulleys results in different warming on the sidewalls of the belt, which is caused by the previously mentioned different friction influence on the active sidewalls of the V-belt. Heat generation is more intensive on the strained sidewalls, however the temperature of the unstrained side could be lower than the values within the error limits.

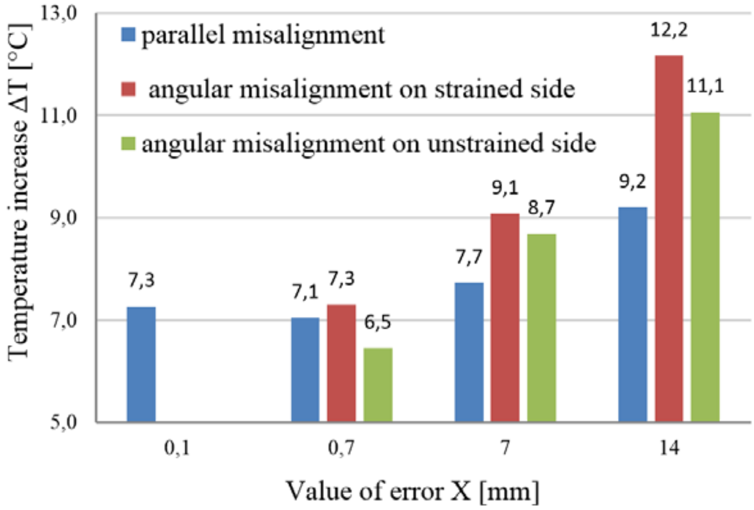

Figure 6: The temperature increase of the V-belt drive due to geometrical adjustment errors as a function of the extent of the error

(SPZ; d_1 *= 150 mm; i = 1;* L_d *= 1207;* f_0 *=15* s^{-1}*;* M_1 *= 8 Nm;* F_H *= 119 N)*

Within the error limits given by the manufacturers no significant difference can be experienced between the temperature increase of the V-belts. Exceeding the permissible error value the V-belts converge to different temperatures.

4. Summary

In this study the losses of V-belt drives were studied through experiments in relation to the adjustment errors of pulleys. The temperature increase of the belt was chosen as the test parameter. Basically the warming of the V-belt is the result of two effects: the heat generated due to the macroscopic friction of the contact surfaces; and the proportion of hysteresis loss occurring due to the repeated strain of the belt which is transformed to heat.

The increased friction conditions, which cause a decrease in efficiency and service life, play a significant role in the temperature increase of V-belts originating from the adjustment errors of pulleys

The major conclusions of V-belt warming tests are the following:

a) The distribution of the temperature is uniform along the belt length, but the temperature is inhomogeneous in the cross-section of the belt, which is caused by inner friction when the belt is being bent repeatedly.
b) The relationship of belt frequency and temperature increase is linear in the studied range.

c) Within the error required by the manufacturers no significant differences can be experienced in temperature increase.

d) In the case of the angular misalignment of shafts the sidewalls of the V-belt converge to different temperatures, which is caused by the different frictional conditions of the active sidewalls of the V-belt.

e) The increased frictional conditions play a role in the temperature increase of the V-belt originating from the adjustment errors of the pulleys.

Within the permissible limits the adjustment error of the pulleys has a favourable effect on the operation of the drive.

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