The evolution of loading capacity in belt transmissions

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Abstract. Belt transmissions were one of the first ways to transfer rotational motion and torque between shafts, and are still remaining in the spotlight for a variety of applications. The paper presents some aspects regarding the efficiency of a flat belt transmission contaminated with starch powder. An original test rig was conceived and built in order to evaluate the loading capacity and efficiency of a flat belt transmission. Using this test rig the values of shafts speeds and the reaction forces generated by the transmitted torque were measured. Several tests were conducted, with and without starch powder as contaminant. The contamination level was evaluated by aid of a particle sensor. Two levels of contamination were applied and the results were compared to those obtained without contaminants. The experimental results reveal that loading capacity of the transmission increases with the concentration of the starch powder.

1. Introduction
Belt transmission is the most common technical solution used to transmit motion between shafts. Recent studies carried out on these transmissions, which are based on the theory of Euler's thin wires [1], attest the constant interest on them. Generally, belt transmissions are used to bring in motion two or more shafts using a continuous cord named belt. Over time, several types of belts were developed: flat belt, “v” belt, poly “v” belt, synchronous belt. Recent studies on these transmissions deal with issues related to: the values of friction coefficients on the dry contact or contaminated pulley-belt surface with various agents [2, 3], the possibilities of optimizing the transmissions in order to increase durability [4, 5], but also with ways of increasing the load capacity [6, 7]. Belt transmissions are used in various applications such as: automotive, agriculture, food industries, entertainment, etc. The oldest category and the cheapest is the flat belt transmission. This type of transmission is used mainly due to its capacity of transmitting motion to multiple shafts with various relative positions, tolerance to the axial orientation of the pulleys and the possibility to transmit with both sides of the belt. Belt transmissions also have several disadvantages, such as: relatively low efficiency compared to other types of transmissions, belt wear, need for periodical adjustment of belt tension, sensibility to contaminants and almost constant transmission coefficient.

The present paper presents a study regarding the efficiency of flat belt transmissions contaminated with starch powder. The contamination of the transmission with starch powder is often found in food industry. Many types of equipment used in food industry possess multiple mechanisms which have to be driven by a single motor. A typical example of such application is in the structure of wheat mills. Due to the milling process, part of the resulting starch powder is driven by air currents and reach the belts and pulleys surfaces. Due to electrostatic effects, the powder adheres to the belt surfaces. In such cases, between the belt and pulleys surfaces a third body appears and the relative friction will be
modified. These mechanisms influence the transmission efficiency and represent the main reason for this study. Figure 1 schematically describes the two studied contact cases between active pulley surfaces and belt.

![Diagram of contact cases between belt and pulley](image)

**Figure 1.** The contaminated and uncontaminated contact between belt and pulley.

2. The experimental setup

A flat belt transmission between two shafts was used. One of the shafts was connected to an electric motor by a coupling in order to eliminate misalignment errors between the motor shaft and the driving shaft. A motor with 1450rpm and 0.37kW was used to drive the transmission.

At the second shaft it is possible to generate a variable resistive torque. The adjustment of the resistive torque was possible by using a disk - brake shoe system. For this purpose, a metallic disk with a diameter of 295 mm was used in conjunction with a brake shoe system. The pressure applied by the brake shoe against the disc is generated by a screw-nut mechanism and the reaction force caused by the friction torque is measured using a device with strain gauges. A second device with strain gauges was used to measure the reaction force generated by the electric motor in order to evaluate the motor torque. The electric motor is mounted on two outer bearings placed on the shaft, as shown in figure 2. The motor housing has the possibility to rotate but its rotational movement is limited by a device fitted with strain gauges, which allows determining the torque.

The mechanical power is transmitted by means of a 2 mm thick and 30 mm wide flat belt. The belt has textile insertion covered with rubber layers. The tension in the belt sides was adjusted by aid of an adjusting mechanism and was considered to be constant during the entire period of the tests. The considered magnitude of the belt tension was 170N and is measured using strain gauges, positioned on the driving shaft pulley.

The rotational speed of the shafts is determined by means of two optical transducers mounted on each shaft.

To simulate the working condition in wheat mills, the transmission was tested in a closed enclosure. An electrical fan was mounted to ensure constant air flow, leading to a relatively uniform disposal of the starch powder. The starch contamination level was evaluated using a particle density sensor. The stand is an upgraded version of one previously developed by the authors in [8]. A representation of the experimental setup is presented in figure 2.

In order to evaluate the angular velocity of the shafts, two optical speed sensors, denoted in figure 2 by 8 and 12, are used. The torque generated by the electric motor is interpreted by the transducer 11, while the resistant one is evaluated by transducer 17. The experimentally measured torques and the angular velocity data can be visualized and recorded by aid of an Arduino Uno development board. It also controls the operation of the electric motor via power relays. For this purpose, a programming code was developed to make it possible to start the electrical engine by serial data communication, but also to automatically stop it when recording a null value of the angular speed at the output shaft. To highlight the degree of contamination of the transmission the dust sensor 20 is used. Further, the whole transmission is placed inside a closed enclosure 19, which is fitted with an electric fan 18 that helps spreading the contaminant.
3. Testing methodology and results
In order to evaluate the mechanical parameters of the motor, correlations motor speed – power, and power – torque, respectively, obtained experimentally are represented in figure 3.

Several tests were conducted at different concentrations of starch particles. The testing procedure starts with a test without starch particles in the closed enclosure. The experimental values of the angular velocity and the reaction forces are recorded. By adjusting the braking force, the transmission load will be modified until sliding effect occurs. The test ends when the second shaft speed becomes null. The correlation between sliding magnitude and transmitted power was highlighted.

For the second test, starch powder was inserted in the closed enclosure. Tests were made with different concentrations of starch powder in order to simulate real working conditions. Two tests were conducted, for particle densities of 296μg/m$^3$ and 485μg/m$^3$, respectively. Particle density was
measured using a SHARP GP2Y10 sensor. For each test, the shafts speeds and the reactions forces were recorded.

Figures 4 and 5 reveal that maximum transmitted power is obtained for the tests with starch powder in the closed enclosure. It was observed that with the increase of particle density, the loading capacity of the transmission also increases. This evolution is due to the melting of powder particles which increase the adhesion effect between belt and pulley surfaces.

The conducted experimental tests showed the transmission efficiency reaches a maximum of 98% for a particle density of 485μg/m³, 93% for 296μg/m³ and 87% for 0μg/m³, respectively. The efficiency of the transmission found to be higher for the tests with starch powder than in the case of clean environment. The maximum of efficiency is obtained for higher values of transmitted torque in the tests with starch powder. Both parameters show a higher loading capacity of the transmission when contaminant is present.

Complete sliding appears at higher values of the transmitted torque in the tests with starch powder. These evolutions also reveal an increase in loading capacity of the transmission.
In order to assess the transmission load-bearing capacity in terms of maximum transmitted power, the evolution of the sliding and efficiency are represented in figure 6 in correlation to the traction coefficient. From this diagram, the critical traction coefficient ($\phi_{cr}$) can be determined. Its value can be found at the intersection of the sliding and efficiency curves for each study case. The maximum transmitted power value ($P_{max}$) in each study case can be calculated by applying equation (1):

$$P_{max} = \phi_{cr} \cdot 2T_0 \cdot v$$

where: $T_0$ is the initial stress on the belt and $v$ represent the peripheral speed.

An analysis of these evolutions shows an increase in maximum transmitted power with the increase of contaminant concentration.

![Figure 6. Transmission characteristic curves.](image)

### 4. Conclusions

The evolution of loading capacity in flat belt transmissions was investigated using an original experimental setup. The belt transmission consists of two parallel shafts with pulleys mounted on them. The mechanical power is transmitted by means of a rubber flat belt. The belt transmission was isolated in a closed enclosure in order to simulate powder contamination conditions. Starch powder was inserted into the closed enclosure and the concentration was measured using a dust sensor. The shafts speeds and the reaction forces were measured and recorded in order to evaluate the loading capacity and efficiency of the transmission.

For the present study, three tests were conducted, with and without the presence of contaminants. The first one was made without starch powder. Two more tests were made at different starch concentrations in the closed enclosure (296μg/m³ and 485μg/m³). The obtained values for shafts speeds and the reaction forces generated by the transmitted torque were compared. The experimental data collected shows that the reaction forces have higher values in the tests with starch contamination for the mentioned experimental conditions. Similar evolutions can be observed in the sliding – transmitted torque correlation. The sliding effect appears at higher values of transmitted torque which indicates a higher loading capacity of the transmission. This manifestation could be explained by the
adherent character of the starch powder which, in low concentration and in the presence of moisture in the air adheres to surfaces and leads to an increase of the wheel-belt relative friction coefficient.

The ratio between output and input powers was correlated with transmitted torque for all tests. This correlation reveals that transmission efficiency increases with starch powder concentration.

The evolutions of the sliding and transmission efficiency show that the starch powder influences these parameters and improves loading capacity for the mentioned experimental conditions. This evolution can be attributed to friction which increases the temperature at the pulley-belt contact surface and probably melts the starch particles. The melted particles act as glue and increase the adhesion effects between belt and pulley. Adhesion between surfaces increases the loading capacity of the transmission.

5. References

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