Construction of an energy efficiency measuring test bench for belt drives

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Abstract

A test bench for the evaluation of the energy efficiency of belt drives is presented. The construction and measurement procedure is discussed with respect to measurement accuracy and reproducibility. Also the impact of additional parameters such as belt tension and misalignment can be analyzed. First measurement results comparing a V-belt drive and a synchronous belt drive are discussed. The efficiency of the drives is measured in the entire operation range and represented by means of iso efficiency maps.

Introduction

Belt drives are still frequently used in industry for the power transmission between electric motor and mechanical load. The power transmission efficiency of such belt drives, according to most references, varies between 90 and 98 percent [1]. These efficiency values are typically related to nominal operation conditions of the belt. Experimental data on belt drive efficiency at reduced speeds and torques are only occasionally reported in literature and recent references are missing.

Belt manufacturers have been very active in research. This has resulted in improved belts with respect to wear, noise and according to the manufactures also efficiency. Unfortunately, efficiency values mentioned by manufacturers are hard to compare. There are no standardized measurement procedures prescribed and catalogs do not mention whether and how the efficiency values have been determined.

Commissioning a belt drive requires manual operations in order to obtain a good and reliable power transmission. Mounting of the pulleys and belts(s) and adjusting the belt tension needs to be performed with care. This is important not only for a reliable operation of the belt drive but also has an impact on the power transmission efficiency. It is well known that belt tension might vary over time resulting in a lower belt tension with respect to the commissioning value. Experimental results to identify the impact of belt tension on efficiency are rare and further research is required to determine if maintenance actions with respect to the belt tension could be justified or required.

This paper contributes to a better understanding of belt drive efficiency. A test bench is discussed which allows to measure power transmission efficiency with adequate precision in the entire operating range of speed and torque. Additional belt drive parameters such as belt tension, misalignment and pulley size can be evaluated as well. Measurement results are represented by means of iso-efficiency contour maps for V-belts drives and synchronous belt drives.

This work is part of a public research project (IWT – Tetra Project) on the efficiency of transmissions (gearboxes and belt drives). This project was preceded by a project on motor and drive efficiency. The next step is to optimize the complete drive train with the gathered knowledge.

Test bench setup

The challenges that come with the construction of a test bench for belt drives are numerous. An overview of the test bench is given in **Figure 1**. One pulley is driven by a 15kW, 4 pole induction machine with a variable speed drive. The second pulley is loaded by means of a second 15kW, 4 pole induction machine in generator mode, also controlled by a variable speed drive. This machine is torque controlled to impress a specific load profile to the belt drive. The DC busses of both variable speed drives are connected in order to limit the energy consumption of the test bench. A schematic overview is given in **Figure 2**.

First, the efficiency must be determined with high accuracy because of low losses in a belt drive. This requires high end measurement devices with high accuracy class. Most test benches for belts use a direct measurement principle. Torque and speed are measured at input and output pulley. Because belt drives use tensioning of the belts, special torque sensors should be used which are not influenced by the radial forces due to belt tensioning. Here, dedicated torque sensors are used for each pulley to overcome this problem (Lorenz Messtechnik MR 12) with a 0.1% full scale accuracy and 200 Nm range. The torque sensors are mounted at the free end of the pulley, avoiding an impact from the radial tensioning force. First measurements revealed the sensitivity of these sensors with respect to the ambient temperature in the test room. The torque sensors were calibrated at 23°C. To correct for different ambient temperatures and different housing temperatures of the torque sensors, thermocouples are used. Furthermore, the test room is equipped with an air-conditioning unit to limit the ambient temperature variation. The setpoint for the ambient temperature is 23°C. Correction of the torque readings with respect to temperature is performed in the data acquisition system of the test bench. The correction table was obtained by performing a static torque measurement for temperatures ranging from 23°C up to 35°C. Pulley speeds are measured by incremental encoders (1024 pulses) mounted on the driving and loading electric motors.

The data acquisition and control of the driving machine and loading machine is performed by means of a dSpace 1103 controller board and a Simulink/ControlDesk interface. For protection reasons, the sensor signals are electrically isolated from the controller board by means of high precision and high bandwidth isolation amplifiers. A calibration of the isolation amplifiers and AD convertors in the controller board has been performed to achieve high accuracy. Calculation of the overall accuracy of the efficiency measurement indicate that the accuracy is less than ±1% for measurements from 200 Nm to about 25 Nm. Durings tests load torques beneath 25Nm are used to acquire complete iso-efficiency contours, but one should take into account an inaccurary of >1% in these lower torque ranges.

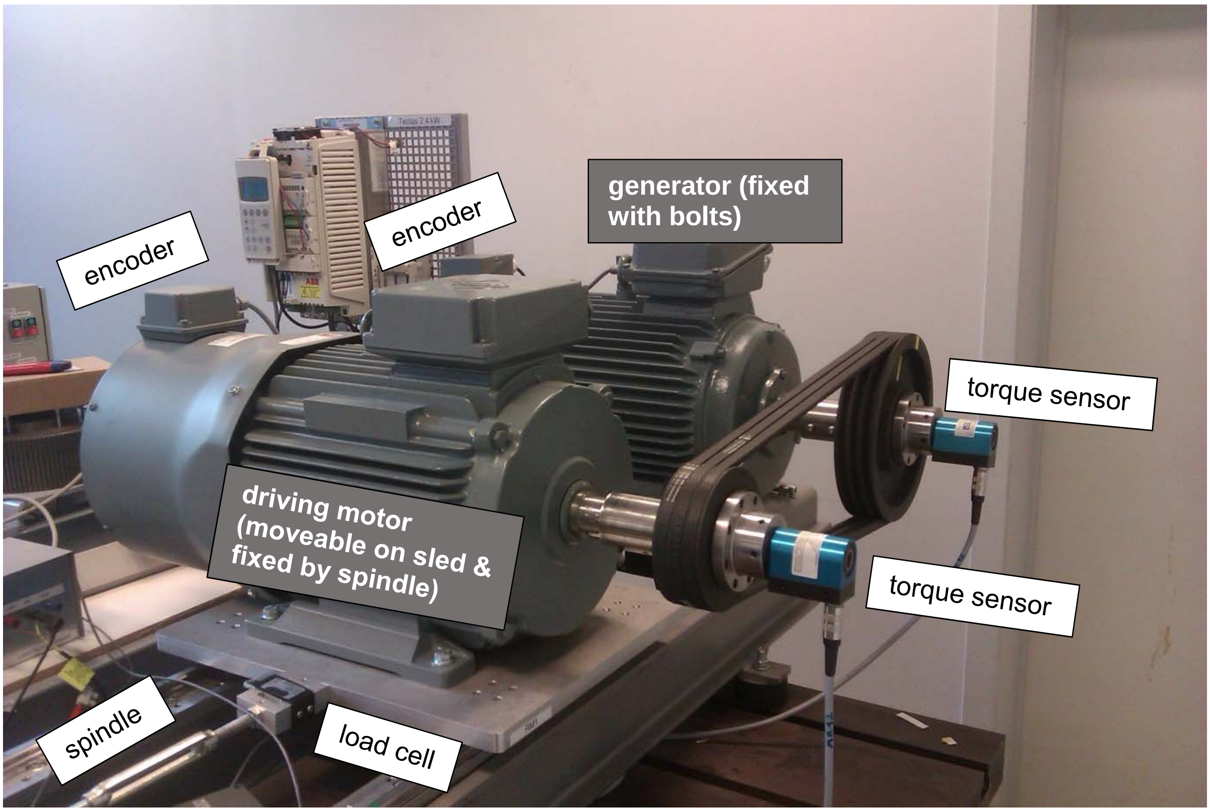

Figure 1: overview of belt test bench

The repeatability of the measurement results is also a major concern. Comparing different belt technologies requires mounting and demounting of belts and pulleys. This mechanical work needs to be performed with great care in order to introduce no additional errors or losses other than the actual belt drive losses. Measurement tools to analyze the misalignment of the pulleys and to check the belt tension are used whenever mechanical changes are required.

To apply a certain belt tension, one of the electric machines can be moved along the belt direction on a sled by means of a spindle (see **Figure 1**). Between the spindle and the electric machine, a load cell is mounted (Sensy 2712, 500 daN). This allows testers to modify the belt tension in a direct way. The load cell is fixed against a 20 mm thick aluminium plate and elongates only 0,35 mm when 500 daN is applied. The spindle is attached to an eye bolt. So theoretically the spindle – and thus the driving motor – could move back and forth because of the eye bolt. But due the tensioning of the belt, the spindle and eye bolt are not moving one to another. Therefor both the load cell and the spindle can be regarded as rigid mechanical components. Other test setups mentioned in literature to adjust belt tension do not show this mechanically rigid construction [2]. In that case, depending on the forces related to the power to transmit, the motor can slightly move. Especially when the belt drive is tested in other than nominal conditions (part load and speed variation) the moving of the machine can result in erroneous results because of a change in belt tension. This is overcome in the test setup described in this paper. If required, the belt tension can also be adjusted when the system is running. In this condition, the belt tension can be recorded by the load cell.

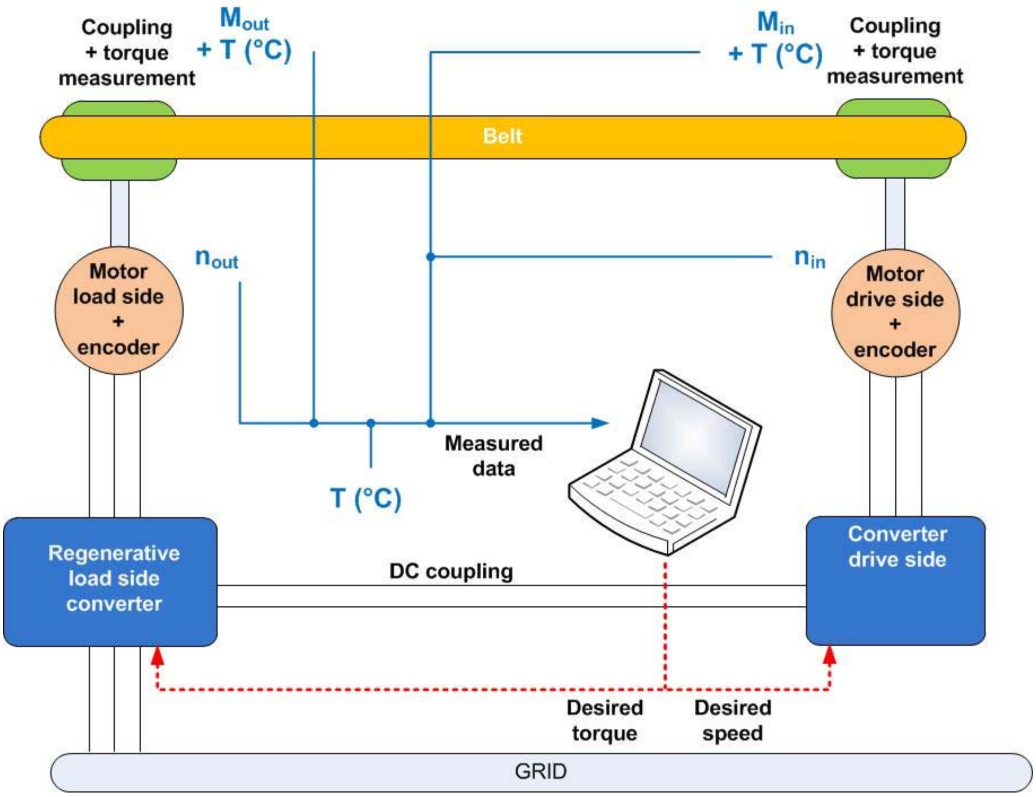

Figure 2: measurement principle belt drive efficiency test bench

Measurement procedure

To guarantee reproducible results, the tests are carried out using a predefined measurement procedure. The procedure starts with a running in of new belts according to the manufacturer's guidelines. Due to possible stretching of a new belt, the belt tension is adjusted typically after one hour of operation. The applied speed and load during running depends on the belt type and the number of belts. If possible, rated torque and speed is applied. Due to torque limitations caused by the motors, some belts cannot be tested in their entire working area.

The first running in test is completed when all system parameters have stabilized (torque signals, temperature readings, etc.). After the first running in test, the setup is shut down and cooled down to ambient temperature again. Then the procedure is repeated at least twice to ensure reproducibility. When the stabilized system parameters of each test are similar, the running in phase is considered done.

In the second step of the measurement procedure, an iso efficiency map is measured starting from a stabilized system. The torque speed region is divided over 16 different speeds and 17 different torque values [3],[4]. This results in 272 operating points to be measured. The measurements start at the highest load and speed allowed by either the belt or test bench. The load is decreased gradually at constant speed until zero. Then speed is lowered, the load is increased to its maximum and decreases again. Before recording the measurements in an operating point, the system is given time to stabilize. When stabilized, 50 measurements are performed in a period of 5 seconds. These results are averaged and result in the efficiency value for the operating point considered.

Performing all measurements to obtain such a detailed iso efficiency map requires about 4 hours. At the moment work is being done to automate these tests. The iso efficiency map itself is created using Matlab.

Another procedure is created to analyze the impact of belt tension on efficiency. First, the belt drive is tensioned correctly, according to the specs, and runs at a fixed speed and load. After one hour the tension is lowered by approximately 25% of its required value expressed in Newton, by looking at the load cell. This cannot be done by measuring the belt frequency because the test bench keeps running to avoid errors. The tension drop is possible due to the drive motor which is on a sled. Again, the efficiency is recorded during an hour and then the test bench is stopped. At that moment the effective frequency is measured with the frequency meter.

Finally, the load side motor can also be moved in order to misalign the pulleys. On a center distance of 60 cm a parallel mistake of 1 cm can be achieved which is an extreme situation. The efficiency measured here is compared to a previous one with correct alignment at the same speed and load. But comparing does imply a risk of enlarging errors as one cannot be sure that all external parameters were the same. This is why the other tests are always done without stopping the test bench. An alternative for testing misalignment is by using double groove pulleys. In the first test the belt is put in a normal position on drive and load side pulley. In the second test, the belt stays on the drive side pulley but is moved to the second groove on the load side. This method limits the risk of inducing mechanical errors. Later in the project, the effect of a belt tensioner will be investigated.

Measurement results

Three parallel matched V-belts type SPA with length of 1682 mm are compared to a 50 mm width timing belt 8M 1800 (synchronous belt). The pulley at the drive side was respectively 140 mm, 56 teeth. At the load side it was 250 mm, 102 teeth. Identical loading for both belt drives is assumed during the test. The choice for this configuration was industry driven.

Figure 3 clearly shows the relation between the efficiency and the applied torque. The impact of speed on the efficiency is shown to be very small. The efficiency at the highest load is 97% which is in accordance to the manufacturer’s documentation.

Figure 4 shows the iso efficiency map for the synchronous belt. The same conclusions on the relation between efficiency and torque can be made. Speed has more impact on the efficiency values compared to the V-belt system. The maximum efficiency here reaches 98%.

To compare the V-belt drive with the synchronous drive in the entire operating range, an efficiency improvement contour can be constructed by subtracting the contour information of the V-belts from the synchronous belt data. The result is shown in Figure 5. For high loads, the synchronous belt is approximately 2% more efficient compared to the V-belt system. If the system is running at low load, the synchronous belt system outperforms the V-belt with approximately 6%. Again, speed seems to have little impact on the efficiency values.

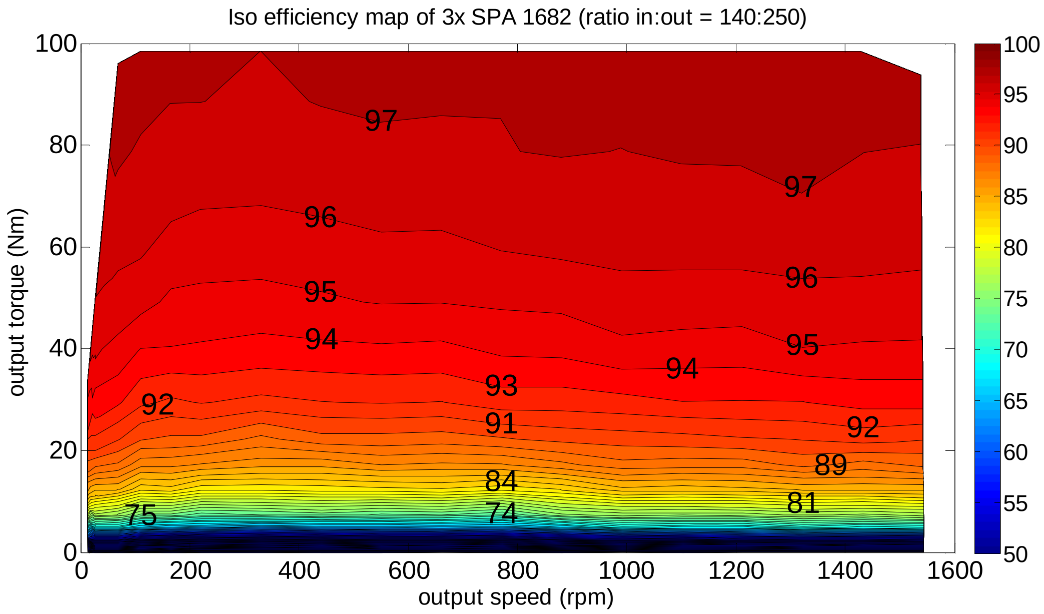

Figure 3: iso efficiency map of 3x SPA 1682

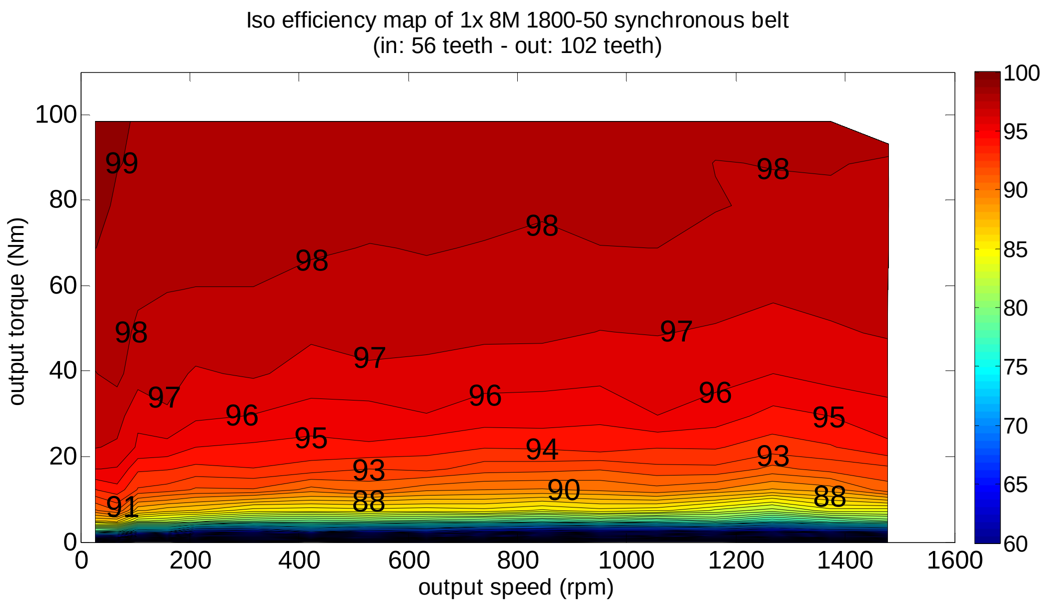

Figure 4: iso efficiency map of 1x 8M 1800-50

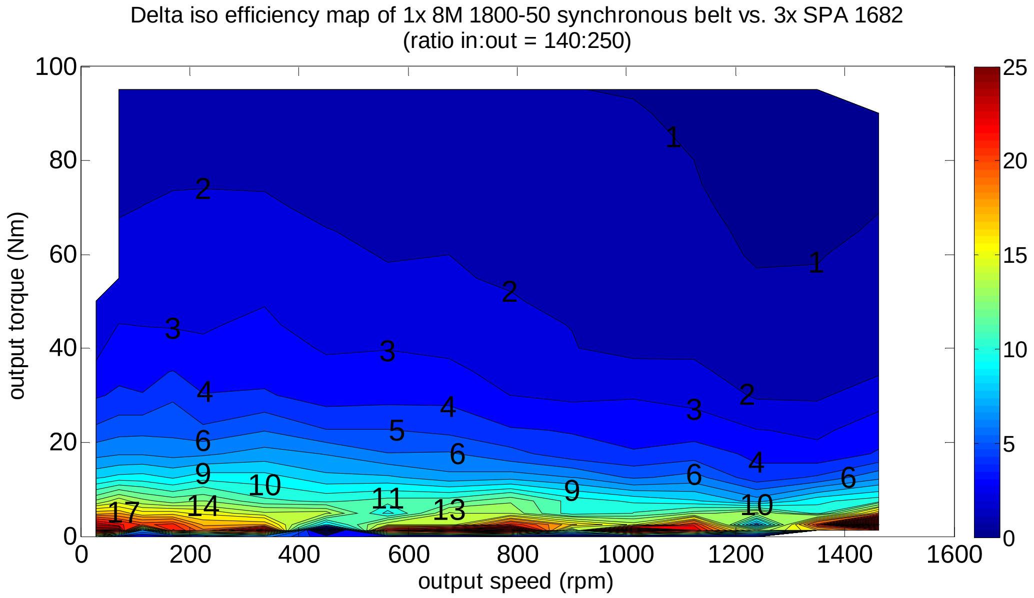

Figure 5: efficiency improvement contour of 1x 8M 1800-50 vs. 3x SPA 1682

Finally in Figure 6 the impact of belt tension at one operating point is shown. Belt tension is in red and the efficiency is in blue. The ripple of about 0,8% on the efficiency is due to the constitution of the belt, which influences the transmitted torque that is used to calculate the efficiency.

Initially, the belt was correctly tensioned with a belt frequency of 33 Hz. After 15 hours of operation the tension was reduced by 33% (in Newton) without stopping the test bench. At hour 21 the test was interrupted as all values were stable. The belt frequency was only 18 Hz, almost 50% lower than recommended. The drop in tension resulted in an efficiency reduction of 1,5%. The test was started up again, without changing the tension. The belt tension was further decreased until the belt slipped audible. The efficiency dropped further as expected. For the lowest belt tension, the efficiency is 2% lower compared to the value with correct belt tension.

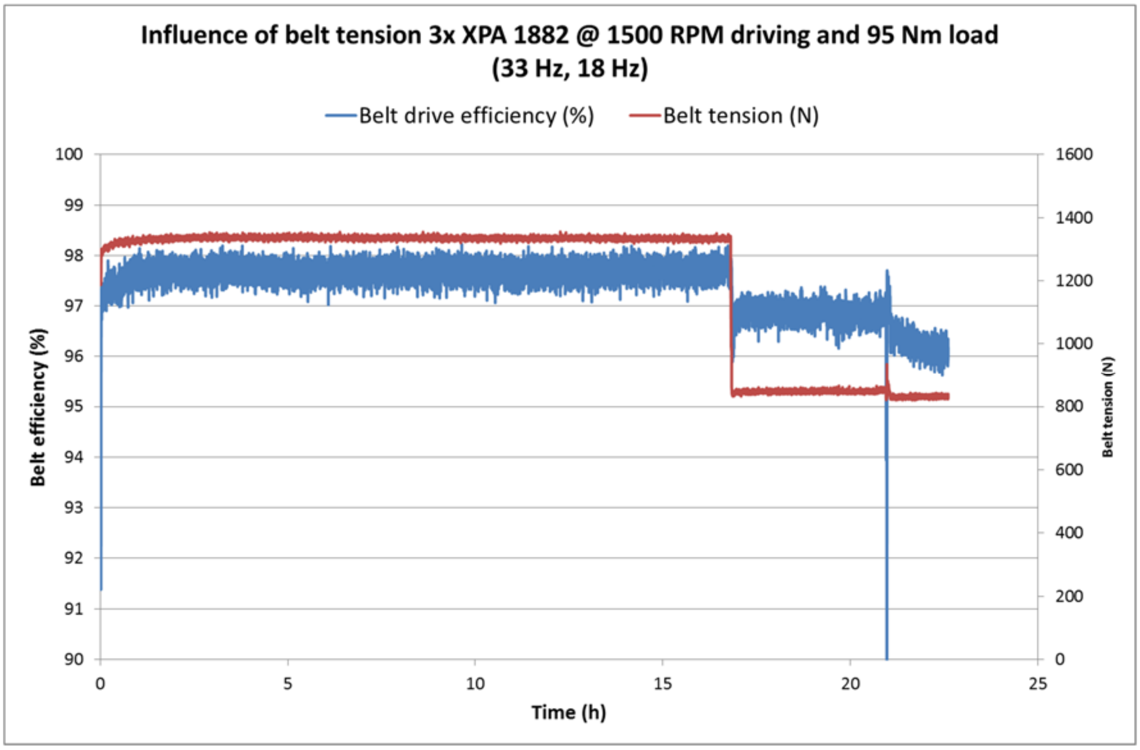

Figure 6: impact of belt tension on efficiency

Conclusion

This paper discusses the construction of a test bench for efficiency evaluation of belt drives up to 15 kW. The required steps to obtain accurate and reproducible efficiency values in the entire operation range are discussed in detail. Also the impact of belt tensioning and possible misalignment of the pulleys can be verified by means of the test bench. Iso efficiency maps are used to analyze the efficiency. First measurement results show that for both V-belts and synchronous belts, the impact of the load torque has a significant impact on efficiency. Speed has a rather limited impact. The measurements also show that the synchronous belt drive is always more efficient compared to the V-belt drive. The lower the loading, the better the synchronous drive performs compared to the V-belt drive. The impact of belt tensioning on efficiency is also measured. Reduced tension results in lower efficiency but the efficiency reduction is lower than is often claimed by producers. Further measurements have to be performed to make conclusions. The test bench has shown to produce reproducible measurement results. Further research will focus on testing a larger number of belts. Finally, to the opinion of the authors, a discussion to define a general measurement procedure related to belt drives could enhance the understanding and the exchange of efficiency data between manufacturers of belt drives and industrial customers.

Usage of a more efficient belt and pulley requires less power from the electric motor to produce the same output torque. Downsizing the motor rating can add to system efficiency and cost.

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