Determination of The Mechanical Power in Belt Conveyor’s Drive System in Industrial Conditions

Robert Król 1, Damian Kaszuba 2, Waldemar Kisielewski 1

1 Faculty of Geoengineering, Mining and Geology, Machinery Systems Division, Wroclaw University of Technology, ul. Na Grobli 15, 50-421 Wroclaw, Poland
2 Faculty of Geoengineering, Mining and Geology, Wroclaw University of Technology, ul. Na Grobli 15, 50-421 Wroclaw, Poland

E-mail: damian.kaszuba@pwr.edu.pl

Abstract. Mechanical power is a value which carries a significant amount of information on the properties of the operating status of the machine analysed. The value of mechanical power reflects the degree of load of the drive system and of the entire machine. It is essential to determine the actual efficiency of the drive system $\eta$ [%], which is the key parameter of the energy efficiency of the drive system. In the case of a single drive of a belt conveyor the actual efficiency is expressed as the ratio of mechanical output power $P_M$ [W] at the drive pulley shaft to active electrical power drawn by the motor $P_E$ [W]. Furthermore, the knowledge about the mechanical power from all drives of the multiple driven belt conveyor allows for the analysis of load distribution between the drives. In case of belt conveyor, the mechanical power $P_M$ [W] generated by the drive at the drive pulley’s shaft is equal to its angular velocity $\omega$ [rad / s] multiplied by the torque $T$ [Nm]. The measurement of angular velocity is relatively easy and can be realized with the use of a tachometer or can be determined on the basis of linear velocity of the conveyor belt during belt conveyor’s steady state operation. Significantly more difficult to perform in industrial conditions is the measurement of the torque. This is due to the operational conditions of belt conveyors (e.g. dustiness, high humidity, high temperature) and tight assembly of the drive components without the possibility of their disassembly. It makes it difficult or even impossible to measure the torque using a number of the techniques available, causing an individual approach to each object of research. The paper proposes a measurement methodology allowing to determine the mechanical power in belt conveyors drives which are commonly used in underground and surface mining. The paper presents result of the research into mechanical power in belt conveyor’s drive carried out in underground mine conditions.

1. Introduction

Currently in Polans, emphasis is placed on improving the energy efficiency of continuous transport machinery. This is due to plans to launch mining of hard coal and copper ore deposits which are located deep and distantly from the existing shafts. Therefore, there is a need to develop new, efficient and economically reasonable solutions of belt conveyor transport. This can be achieved mainly through a reduction of the main resistance to motion of the conveyor which is specified by the main resistance coefficient $f$, [1].

The greatest energy savings can be expected with a reasonable selection of belt and idlers and optimal selection of the carrying idler sets spacing, and in some cases also in unconventional solutions.
of belt conveyors routes, drives, tensioning devices and transfer chutes [2-6]. A significant impact on
the improvement of energy efficiency of belt conveyor has also high efficiency of drive determined
on the basis of a comparison of mechanical power with the active electrical power. The belt conveyor’s
drive efficiency, among others, is a factor determining the energy consumption of current and future
design solutions of belt conveyors.

Active electrical power $P_e$ [W] drawn by a single motor in drive system can be determined on the
basis of measurements of electrical input power, voltage drops on each of three electrical phases and
phase angle $\phi$. Carrying out this type of measurements does not pose any particular difficulties.
Mechanical power $P_m$ [W] generated by the drive at the drive pulley’s shaft is equal to its angular
velocity $\omega$ [rad/s] multiplied by its torque $T$ [Nm]. The measurement of angular velocity is relatively
easy and can be realized with the use of a tachometer or can be determined on the basis of linear
velocity of the conveyor belt during belt conveyor’s steady state operation. Significantly more difficult
to perform in industrial conditions is the measurement of the torque. This is due to the operational
conditions of belt conveyors (e.g. dustiness, high humidity, high temperature) and tight assembly of
the drive components without the possibility of their disassembly.

Currently used measurement techniques allowing for the determination of torque at drive pulley’s shaft of belt conveyor require the use of e.g.:
- load cell – involving the use of load cell holding the moment arm of the drive [7, 8, 9],
- torque (sensor) transducer – involving the use of special torque transducer installed as
  a new element of drive’s power transfer chain [8, 9, 10],
- strain gauges - involving the use of strain gauges installed at drive pulley’s shaft [8, 9, 11],
- code disks – involving the use of code disks which relative displacement allows to determine
  shaft’s twist angle [8, 9, 12],
- FAST method – involving the use of magnetostriction phenomena [8, 9].

In the view of belt conveyor’s operational and assembly conditions in-situ the own method was
proposed for determination of drive pulley’s shaft torque. The proposed method is based on the use of
strain gauges installed on reaction element immobilizing belt conveyor’s drive which are commonly
used in belt conveyors drives.

2. Concept of determining mechanical power

In the proposed method, mechanical power transmitted to the drive pulley’s shaft of a single drive of
belt conveyor is determined on the basis of its torque and angular velocity on the basis of relation:

$$P_m = M_S \cdot \omega \text{ [W]}$$  \hspace{1cm} (1)

where: $P_m$ – mechanical power, in W, $M_S$–torque, in Nm, $\omega$ – angular velocity, in rad/s.

The angular velocity of drive pulley’s shaft in relation (1) will be determined on the basis of measured linear velocity of conveyor belt $v_t$ [m/s]. In order to determine the torque $M_S$ (relation 1) the
reaction element immobilizing the drive will be used. Different solutions of reaction elements are
commonly used in belt conveyor in both underground and surface mining. Belt conveyor’s drive on
one side is mounted on the drive pulley’s shaft and on the other side is supported by the reaction
element in articulate way. Due to this way of support the reaction element transmits only the
longitudinal forces. The $F_l$ force acting on reaction element at moment arm $L_l$ compensates the torque
$M_{sl}$ transferred from the gear onto drive pulley, shown in Figure 7, therefore the torque can be
determined from following relation:

$$M_S = F \cdot L \text{ [Nm]}$$  \hspace{1cm} (2)

where: $M_S$– torque [Nm], $F$- longitudinal force on reaction element [N], $L$- moment arm length, [m].

Figure 1 shows the scheme of drive station of belt conveyor driven by two pulleys with the idea of
determining torque with use of reaction elements.
Figure 1. The scheme of drive station of belt conveyor driven by two pulleys with the idea of determining torque

The length of moment arm \( L \) in relation (2) is determined on the basis of technical documentation of belt conveyor and verified in-situ. Before the measurements in industrial conditions the reaction element was delivered at Wroclaw University of Science and Technology for the strain gauges’ installation in laboratory conditions. During the strain gauges’ installation, the following steps were taken to ensure the best possible quality of the measurements: preparation of reaction element’s surface, bonding (gluing) the strain gauges to the reaction element, connecting strain gauges electrically, calibration of reaction element and application of protective layers. Preparation of reaction element according with mentioned steps allows the reaction element to be used for determination of \( F \) force in relation (2) in operational conditions. View of reaction element during preparation steps is shown in Figure 2.

Figure 2. Steps of strain gauges’ installation: a) preparation of reaction element’s surface, b-c) with bonded (glued) strain gauges, d) with applied protective layers

Figure 3 shows the reaction element during calibration and result of calibration of reaction element.
Before manufacturing reaction elements, the stress analysis was performed in order to verify the stress distribution before the strain gauges’ installation. The analysis was performed accordingly to Saint-Venaint’s principle [13]. The aim of the analysis was to identify the optimal diameter of reaction element, which is the most suitable for strain gauge installation. The limitation was the length of the reaction element which could not be changed. The results of the conducted analysis are shown in Figure 4. Comparing the results of stress analysis of reaction element with diameter of 80 mm and diameter of 60 mm it should be noted that the use of reaction element with diameter of 60 mm is preferable from strain gauge point of view because of more uniform stress distribution. Moreover, the 60 mm diameter of reaction element offers higher sensitivity.
3. Determination of mechanical power in belt conveyor drive system

Research into mechanical power were carried out for drive system of belt conveyor operating in underground copper ore mine equipped with two drives with capacity of 250 kW each. The scheme of drive station is shown in the Figure 1. Research were carried out with the use of two reaction elements prepared accordingly to the described concept. Reaction elements were installed into belt conveyor’s drive in operational conditions and connected to the Data Acquisition System, it is shown in Figure 5. Torque and mechanical power at the drive pulley’s shaft were determined on the basis of relation (1) and (2) for constant linear velocity of conveyor belt $v_t = 2.29$ m/s.

![Figure 5. View of reaction element installed in belt conveyor’s drive](image)

Figure 5 shows the variation of instantaneous values of $F_1$ and $F_2$ (Figure 1) forces determined with the use of reaction elements.

![Figure 6. Exemplary traces of $F_1$ and $F_2$ forces determined with use of reaction elements](image)
Figure 7 shows the variation of instantaneous values of torque $M_{s1}$ and $M_{s2}$ (Figure 1) determined for drive pulleys shafts.

![Figure 7](image1.png)

**Figure 7.** Exemplary traces of instantaneous torque $Ms1$ and $Ms2$ (Figure 7) determined for drive pulleys shafts

Figure 8 shows the variation of instantaneous mechanical power $P_{M1}$ and $P_{M2}$ determined for drive pulleys shafts.

![Figure 8](image2.png)

**Figure 8.** Exemplary traces of instantaneous values of mechanical power $P_{M1}$ and $P_{M2}$ determined for drive pulleys shafts

### 4. Conclusions
- The paper presents method of determination of mechanical power at belt conveyor’s drive pulley’s shafts proposed by Machinery Systems Division of Wroclaw University of Science and Technology. Presented method proved itself to be valuable and passed the test in industrial conditions in underground copper ore mine.
• Reaction elements equipped with strain gauges accordingly to the presented concept can be applied for determination of mechanical power in belt conveyors operating in various operational conditions. It is due to the fact that different solutions of reaction elements are commonly used in belt conveyors.
• By comparing the determined mechanical power with active electrical power it is possible to determine the actual efficiency of the belt conveyor’s drive. The actual efficiency of belt conveyor’s drive is an important factor determining belt conveyor’s energy consumption.
• For the purpose of use of strain gauges, the influence of the reaction element diameter on its stress distribution was analysed. Conducted analysis allowed to determine improved diameter and manufacture reaction element with uniform stress distribution and its higher sensitivity comparing to the base diameter of reaction element.
• Traces of instantaneous mechanical power $P_{m1}$ and $P_{m2}$ show that both drives are loaded approximately equally.

Acknowledgement(s)
This paper was financially supported partly by the Polish Ministry of Science and Higher Education as scientific project granted for year 2016.

References
[1] Gladysiewicz L., Hardygóra M., Kawalec W., 2009. Determining belt resistance, Bulk Handling Today, vol 5: 23 - 28
[2] Gladysiewicz L., 2003. Przenośniki taśmowe Teoria i obliczenia, Oficyna Wydawnicza Politechniki Wrocławskiej, Poland
[3] Gladysiewicz L., Kawalec W., Król R., 2016. Selection of carry idlers spacing of belt conveyor taking into account random stream of transported bulk material. Eksplatacja i Niezawodnosć – Maintenance and reliability; 18 (1):. 32 - 37
[4] Król R., 2013. Metody badań i doboru elementów przenośnika taśmowego z uwzględnieniem losowo zmiennej strugi urobku. (Methods of testing and selection of the belt conveyor equipment with regard to random loading of a transported bulk material, in Polish), Oficyna Wydawnicza Politechniki Wrocławskiej, Poland
[5] Król R., Kisielewski W., Kaszuba D., Gladysiewicz L., 2015. Laboratory Tests of Idlers Rotational Resistance – Selected Issue, Journal of Procedia Earth and Planetary Science, vol. 15:. 712 - 719, http://dx.doi.org/10.1016/j.proeps.2015.08.100
[6] Król R., Kisielewski W., Kaszuba D., Gladysiewicz L., 2016. Testing belt conveyor resistance to motion in underground mine conditions, International Journal of Mining, Reclamation and Environment, http://dx.doi.org/10.1080/17480930.2016.1187967
[7] Honeywell, 2006. Ways to Measure the Force Acting on a Rotating Shaft. Honeywell International Inc. https://measurementsensors.honeywell.com/techresources/appnotes/Pages/Ways_to_Measure_the_Force_Acting_on_a_Rotating_Shaf.aspx
[8] Naruszkiewicz W., 2005. Pomiary momentu obrotowego, (Measurements of the torque, in Polish), Automatyka B2B, http://automatykab2b.pl/technika/760-pomiary-momentu-obrotowego#.V2hMCvmLSHs
[9] Sadowski A., Zółtkowski B., 2012. Bezinnwazyjne metody pomiaru momentu obrotowego, (Non-invasive methods for measuring torque, in Polish), Logistyka, 6:914 - 924
[10] Bieńkowski A. Szewczyk R., Salach J., 2010. Industrial Application of Magnetoelastic Force and Torque Sensors, ACTA PHYSICA POLONICA A, Vol. 118:1008 - 1009
[11] Decner A., Iskierski L., 2015. Pomiar momentu obrotowego w warunkach przemysłowych, (Torque measurement in industrial conditions, in Polish), Napędy i Sterowanie, 7/8:139 - 143
[12] Barszcz T., Urbanek J., 2010. Dynamiczny pomiar mocy maszyn wirnikowych, (Dynamic power measurement of rotating machinery), PAK, Vol. 56:483 - 486.
Gere, J., Goodno, B., 2008. Mechanics of Materials. Cengage Learning, USA, 163 - 168 p