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FOLLOW-UP CHAIN TENSION IN AN ARMOURED FACE CONVEYOR

NADĄŻNE NAPINANIE ŁAŃCUCHA ZGRZEBŁOWEGO W PRZENOŚNIKU ŚCIANOWYM

Initial chain tension in armoured face conveyors, in which operating conditions vary constantly, should be adjusted automatically to adapt it to the needs arising. The manufacturers of such conveyors are now offering a possibility of equipping a conveyor with a drive with a telescopic trough enabling stepless change of the scraper chain contour by shifting the drive frame. The work presents the outcomes of computer investigations performed using an own mathematical model of an armoured face conveyor with a main and auxiliary drive equipped with a telescopic trough and an automatic initial chain tension adjustment system with the ASTEN algorithm. The ASTEN algorithm is responding to changes in scraper chain elongation caused by changes to conveyor configuration and also by a varying mined coal load resulting from interworking with a mining machine.

Keywords: scraper conveyor, AFC dynamics, dynamic loads, initial chain tension, follow-up chain tension

W czasie ruchu przenośnika ścianowego łańcuch zgrzebłowy ulega wydłużeniom sprężystym. Wartość tych wydłużeń jest zmienna i zależy między innymi od oporów ruchu oraz występujących drgań. W celu kompensacji wydłużeń sprężystych łańcucha zgrzebłowego jest on obecnie napinany wstępnie w czasie postoju maszyny. Wartość wymaganego napięcia wstępnego ustala się na podstawie największych przewidywanych obciążeń występujących w ruchu ustalonym przenośnika. Nastawione napięcie wstępne łańcucha zmienia się jednak stale w czasie ruchu.

Na skutek licznych, stale zmieniających się czynników występujących w czasie eksploatacji, wymagane (dla danych warunków ruchu i obciążenia nosiwem) napięcie wstępne łańcucha prawie nigdy nie odpowiada napięciu wstępnemu zadanemu. Ponieważ w przenośnikach ścianowych warunki eksploatacyjne ulegają ciągłej zmianie, napięcie wstępne łańcucha powinno być do nich dostosowywane, a osiągnąć to można tylko przez regulację automatyczną.

Producenci przenośników ścianowych oferują obecnie możliwość wyposażenia przenośnika w napęd z rynną teleskopową, dający możliwość bezstopniowej zmiany długości konturu łańcuchowego przez przesuwanie kadłuba napędu. Ze względu na stosowanie w napędach pomocniczych (zwrotnych) wyłącznie pojedynczych zespołów napędowych, rynny teleskopowe za pomocą siłownika hydraulicznego przesuwają najczęściej kadłub tego napędu.

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Przenośnik zgrzebłowy ścianowy wyposażony w układ nadążnego napinania łańcucha zgrzebłowego powinien w czasie pracy w wyrobisku ścianowym stale rejestrować i analizować takie parametry pracy, które pozwolą na wypracowanie sygnału sterującego siłownikiem hydraulicznym w rynnie teleskopowej umieszczonej w napędzie pomocniczym. Zadaniem siłownika jest takie przemieszczenie kadłuba napędu pomocniczego, aby uzyskać pożądaną wartość napięcia wstępnego łańcuchów.

Utworzony algorytm sterowania nadążnym napinaniem łańcucha, który nazwano ASTEN, składa się z dwóch modułów: ASTEN/C i ASTEN/P.

Moduł ASTEN/C analizuje sygnały sterujące z czujników zwisu łańcucha w napędzie głównym oraz z czujników położenia zgrzebeł w napędzie pomocniczym. Z analizy kombinacji wszystkich sygnałów z czujników zwisu łańcucha przy zbieganiu z bębna napędu głównego oraz czujników położenia zgrzebeł umieszczonych w miejscu zbiegania łańcucha z bębna łańcuchowego w napędzie pomocniczym do algorytmu sterowania nadążnym napinaniem łańcucha zgrzebłowego wchodzą sygnały logiczne informujące o stanie napięcia łańcucha w miejscach jego zbiegania z bębnów napędowych. Algorytm ten uśrednia sygnały wejściowe i co t_C sekund wylicza wartość przesunięcia kadłuba napędu na podstawie podanych parametrów przenośnika.

Moduł ASTEN/P analizuje sygnały z przekładników prądowych. Wzrost obciążenia napędów przenośnika wywołany jest głównie wzrostem oporów przesuwania urobku. Wydłużenia sprężyste łańcucha zgrzebłowego w zasadniczy sposób wynikają z obciążenia przenośnika oporami przesuwania urobku w stronę napędu głównego, które zależne są od masy urobku na przenośniku i sposobu jej rozłożenia na długości przenośnika, współczynnika oporów tarcia urobku o rynnę, kąta podłużnego nachylenia rynnociągu w wyrobisku i zmienności tego kąta na długości przenośnika. Ten moduł algorytmu wyznacza wartość przesunięcia kadłuba napędu spowodowanego wzrostem obciążenia silników napędowych co t_P sekund.

W pracy zaprezentowano wyniki badań komputerowych, z wykorzystaniem własnego modelu matematycznego przenośnika ścianowego z napędem głównym i pomocniczym wyposażonego w rynnę teleskopową oraz układ automatycznej regulacji napięcia wstępnego łańcucha zgrzebłowego za pomocą algorytmu ASTEN. Algorytm ASTEN reaguje na zmiany wydłużeń łańcucha zgrzebłowego związane ze zmianą konfiguracji trasy przenośnika oraz spowodowane zmiennym obciążeniem urobkiem węglowym wynikającym ze współdziałania z maszyną urabiającą.

Słowa kluczowe: przenośnik ścianowy, dynamika przenośnika, obciążenia dynamiczne, napięcie wstępne, nadążne napinanie

1. Introduction

In connection with the existing tendency to reduce hard coal extraction costs and strengthen production competitiveness per face, the load is constantly rising on longwall machines in which, owing to the research carried out, innovative solutions and construction modifications are implemented (Broadfoot & Betz, 1996; Dolipski et al., 2012; Dolipski & Remiorz, 2001; Gumuła, 2005; Krauze & Kotwica, 2007; Krauze, 2004; Szweda, 2001), (Zhang Chunzhi & Meng Guoying, 2011). Armoured face conveyors are the essential machines forming part of longwall systems. They are the only means of transporting mined coal from longwalls. The length of face conveyors may exceed 400 m with the installed capacity of drive motors of 2 × 1000 kW. The high performance face conveyors currently in use reach the efficiency of more than 10,000 tonnes per day (Traud, 2005).

A scraper chain is subject to elastic elongation during the movement of a face conveyor. The value of such elongation is variable and depends, in particular, on motion resistance and the occurring vibrations. In order to set off spring elongations of a scraper chain, it is initially tensioned during machine stoppage. The required initial tension value is determined based on the highest predictable loads existing for the set motion of the conveyor. The set initial chain tension is, however, changing constantly in motion. The set initial tension may be increased by such factors as horizontal and vertical tilting of troughs, or conveyor shift. On the other hand, the preset initial tension value may be affected by excessive loading with the material handled, by contamination of the lower section of troughs or by permanent elongation of links caused by abrasive wear in joints. Due to numerous, constantly changing factors taking place in operation, the chain initial tension required (for given operational conditions and for loading with material handled) almost never corresponds to the set initial tension (Dolipski, 1997). As operating conditions in face conveyors vary constantly, initial chain tension should be adjusted accordingly to such conditions, and this can be accomplished through automatic adjustment only.

The manufacturers of face conveyors are now offering a possibility of equipping a conveyor with a drive with a telescopic trough enabling stepless change of the chain contour length by shifting the drive frame. As single drive units are used only in auxiliary (return) drives, telescopic troughs are usually shifting the drive frame by means of a hydraulic actuator.

Attempts were already made in the past to create automatic systems for initial chain tension adjustment in face conveyors. The work (Wiechers, 1986) describes an automatic adjustment system of initial chain tension by changing the distance between chain drums. An input signal for the adjusting mechanism was represented by chain slackening in the main (dumping) drive and by the distance between chain links in the branch running by the auxiliary (return) drive. Measuring heads reacting to magnetic field variations are mounted for this purpose in the surrounding of the chain drums. A measuring signal was supplying mass distribution of the scraper chain in the measuring area of the heads. Depending on the measuring signal value, the adjusting mechanism was evaluating the tension condition of chains and was controlling the contraction and extension of the tensioning telescopic trough. This solution, however, did not prove itself in difficult mining operating conditions and works over the solution were ceased at the end of the 80's of the twentieth century.

The work (Dolipski & Remiorz, 2001) presents a system of follow-up change of residual initial chain tension NRW, in which an input signal to the automatic system was the value of residual initial tension of chains in the place where the chain was unwinding from the drive drum ΔS_0. The chain contour length was changing by shifting the frame of the main drive and/or auxiliary drive. The value of residual initial tension of chains in the place where the chains unwound from the drive drum was selected as a control signal as it allows to identify clearly the dynamic status of a scraper chain (the condition of constant chain slackening, the condition of periodical chain slackening and condition of non-slackening). Extensive computer investigations were carried out using a mathematical model of an armoured face conveyor which proved the operational efficiency of the algorithm. The value of residual initial tension of chains is, however, only a theoretical signal. Thus, the method cannot be practically used at present.

R&D works have been taken by a number of scientific institutions around the world, the outcomes of which should allow to use the working parameters of a face conveyor enabling to effectively use the follow-up scraper chain tensioning in the algorithm.

2. Follow-up chain tensioning control algorithm ASTEN

An armoured face conveyor equipped with a follow-up scraper chain tensioning system should, while working at a longwall, constantly record and analyse such working parameters which would allow to develop a control signal for a hydraulic actuator in a telescopic trough placed in an auxiliary drive. The task of the actuator is to move the auxiliary drive frame in such a way as to obtain the desired value of initial chain tensioning. The follow-up chain tensioning control algorithm called ASTEN envisages that a conveyor is to be equipped with the following measuring elements:

- Chain slackening sensors mounted in the main drive (A).
- Scraper position sensors mounted in the auxiliary drive (B).
- Current transformers allowing to register the intensity of currents drawn by all drive motors of the conveyor depending on temporary loading with mined coal and motion resistance existing and temporary distribution of loads into particular motors.

By taking such assumptions, a chain initial tension control algorithm consisting of two modules ASTEN/C and ASTEN/P (Fig. 1) could have been established.

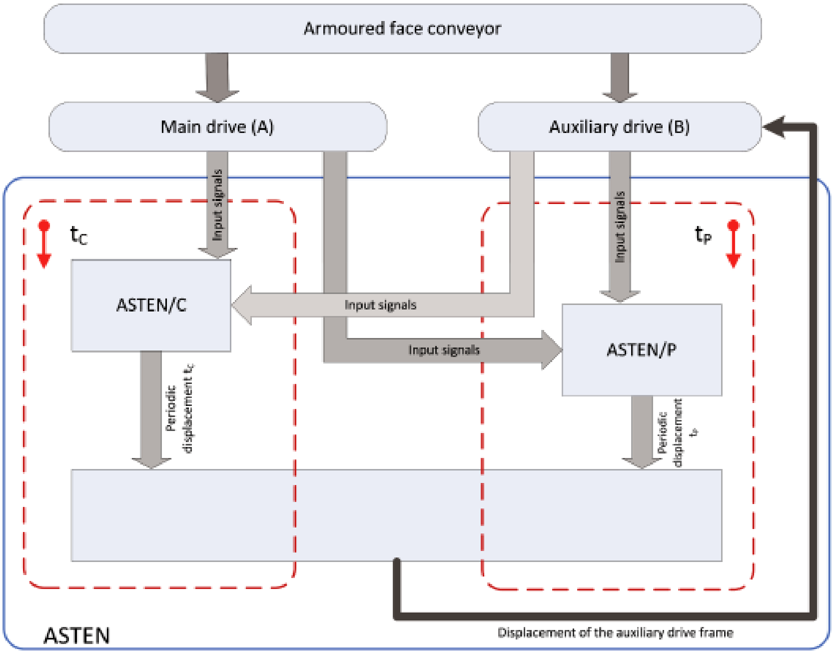

Fig. 1. Operating diagram of the follow-up chain tensioning control algorithm ASTEN in a face conveyor

The ASTEN/C module is analysing control signals from the chain slackening sensors in the main drive and from the scrapers position sensors in the auxiliary drive. Logic signals informing about the chain tensioning condition in the place where the chain is unwinding from the drive drums are fed from an analysis of combination of all signals from the chain slackening sensors when unwinding from the drive of the main drive and from the scrapers position sensors situated in the place where the chain is unwinding from a chain drum in the auxiliary drive. This algorithm is averaging input signals and calculates, every t_C seconds, the drive frame shift value based on the given conveyor parameters.

The ASTEN/P module is analysing signals from current transformers. Growth in the load on the conveyor drives is caused mainly by the growing motion resistance of mined coal. Elastic elongation of the scraper chain is resulting principally from loading the conveyor with motion resistance of mined coal towards the main drive, which is dependent on the mass of the mined coal located on the conveyor and on the way it is distributed along the conveyor, on the friction coefficient of the mined coal against the trough, the angle of longitudinal pan line inclination in the heading and the variability of such angle along the conveyor. This module of the algorithm determines the drive frame shifting value caused by increased load on the drive motors every t_P seconds.

The ASTEN/P module uses the ranges of values of current intensity referred to the nominal value. The range of the current load of motors was divided into p_{ob} intervals separated with threshold values. When the threshold value of current intensity is exceeded, the algorithm is taking measures to calculate an auxiliary drive frame shift value and to extend the actuator piston rod when transiting from a lower to a higher range or to draw the actuator piston rod when transiting from a higher to a lower range. No measures are taken by the ASTEN/P algorithm if the threshold value is not exceeded as a result of changes in current intensity within any range. The control algorithm is acting analogously if signals of the power reached by drive motors are used for determining the conveyor load level instead of current signals.

Measurement of current intensity reflecting the load level of the conveyor drives is not determining, however, the values of elastic elongation of the scraper chain, which are substantially dependent on the position of the mined coal stream along the conveyor. The position of the mined coal stream is determining the length of the chain section in the upper branch, which is elongated elastically.

Elastic elongation of the scraper chain is substantially dependent not only on the length of the mined coal stream l_{ur}, but also on its position on the conveyor. This is presented for two extreme variants of the mined coal stream position: when unloading a conveyor on the main drive and when loading a conveyor from the auxiliary drive side on figures 2 and 3.

As no information about the mined coal stream position on the conveyor is available while a face conveyor is operating, the mined coal stream position on the conveyor is considered using the coefficient w.

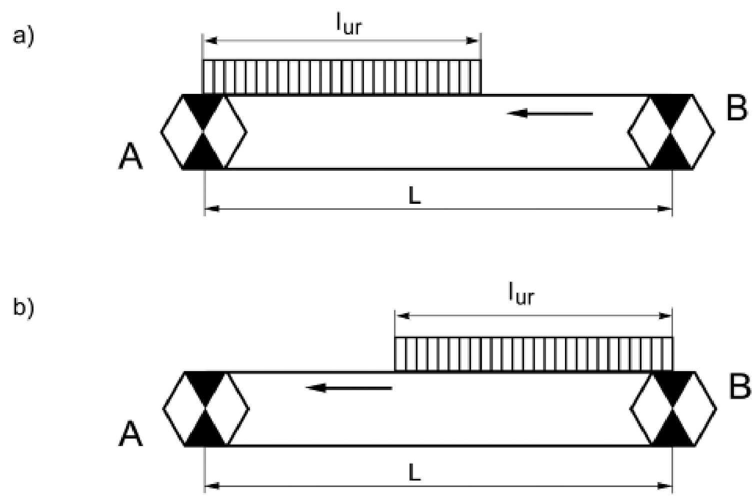

Fig. 2. Changes in the mined coal stream length on the conveyor: a) unloading, b) loading

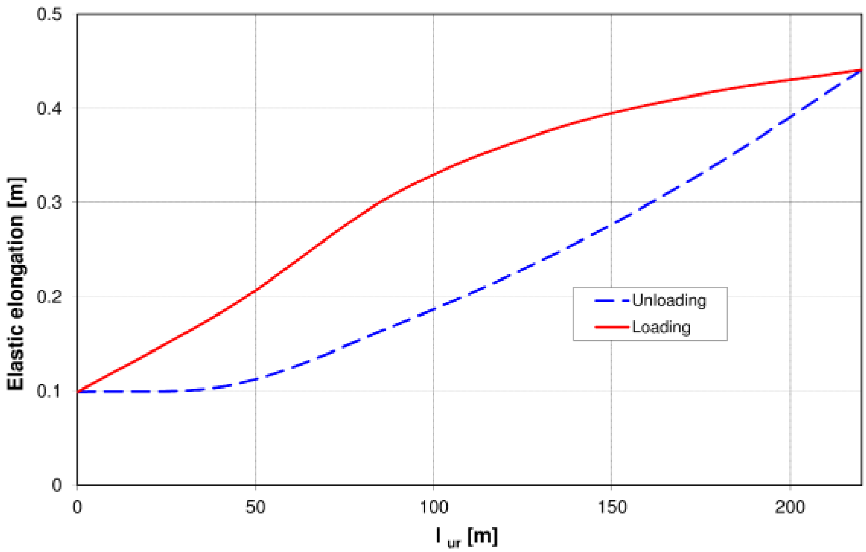

Fig. 3. Elastic elongation of the scraper chain during unloading and loading of a face conveyor

The elongation value of the chain caused by increased load on the main drive equipped with one drive motor in a given load range considers the mined coal stream position on the conveyor with the elongated part of the chain dependent on it and is determined according to the two dependencies:

$$\Delta L_A = \frac{N_{SA1N} \cdot w_k \cdot L}{p_{ob} \cdot 2 \cdot v \cdot E_0} \tag{1}$$

where:

- ΔL_A — chain elongation caused by increased load on the main drive within the given range,
- N_{SA1N} — nominal power of motor in the main drive,
- w_k — coefficient of mined coal position on the conveyor in the *k*-th load range,
- L — conveyor length,
- v — scraper chain speed,
- E_0 — chain link rigidity,
- p_{ob} — number of load ranges.

The values of coefficients of mined coal position on the conveyor were determined according to the mined coal position in different zones of the conveyor upper branch and on the loading frequency of such zones with mined coal. It was assumed here that the average loading of the upper branch of the conveyor with mined coal on the section equivalent to L/p_{ob} of the conveyor length corresponds to L/p_{ob} of the motors‘ power available after overcoming motion resistance of the scraper conveyor without the mined coal. The mined coal conveyor position coefficient according to the mined coal position in different zones of the conveyor upper branch in a given load range of the ASTEN/P algorithm and the loading frequency of such zones with mined coal was determined as a weighted mean of the distance of the centre of gravity of the mined coal situated in the upper branch from the conveyor main drive (which is corresponding to the length of the elongated chain section) and the loading frequency of the given zone. The coefficient value of mined coal position on the conveyor for p_{ob} load ranges separated with threshold values is in the k-th load range depending on:

$$\overset{k=p_{ob}}{\underset{k=1}{w_k}} = \sum_{i=1}^{i=p_{ob}-k+1} \frac{i-1+\frac{k}{2}}{p_{ob}} \cdot \frac{p_{ob}-k-i+2}{\sum\limits_{j=1}^{j=p_{ob}-k+1} j} \tag{2}$$

The shift values calculated by the ASTEN/C and ASTEN/P modules are passed to the block where the shift value of the auxiliary drive frame is finally determined. This value is passed on to the executive element controlling the shifting of the telescopic trough.

The possible combinations of logic signals incoming to the control algorithm of scraper chain follow-up tensioning from sensors when the chain is unwinding from the main drive and auxiliary drive and from current transformers is decisive for sending or not sending a signal to the actuator of the telescopic trough to obtain the optimum chain tensioning condition for the given working conditions of a face conveyor.

3. Computer investigations

An own dynamic model of a face conveyor with a main and auxiliary drive with variable chain contour length was used for computer investigations of the ASTEN algorithm operation. Stepless adjustment of initial chain tension values was modelled with a movable auxiliary drive frame, the location of which is described with a translation coordinate x_B. The frame is moved by means of a telescopic trough and hydraulic actuators.

The computer investigations simulated the operation of a 220 m long face conveyor with fixed frames of the drives ($\dot{x}_B = 0$ m/s) loaded along the entire length with a mined coal stream at the rate of 160 kg/m. The nominal power of the motors installed in the main and auxiliary drive was 2 × 315 kW. Initial tension of 140 kN was set for each chain during conveyor stoppage.

The start-up time of the so configured conveyor was about 1 second. A scraper chain was in the non-slackening state and the maximum dynamic load value in the chain in the place where the chain is unwinding from the chain drum in the auxiliary drive in the set motion was equal to 71,6 kN (Fig. 4). The maximum value of mechanical power consumed by the main drive and auxiliary drive was 433,7 kW.

Computer simulations of motion in the conveyor for the non-slackening state of chains were carried out for the following assumptions:

- Conveyor start-up takes place with the upper branch loaded with mined coal along its entire length.
- The upper branch is unloaded along the set length in the conveyor's set motion in the fifth second of simulation. It is somewhat simplified and this allows to present the influence of conveyor unloading on the corresponding time characteristics on one diagram.
- The length of the mined coal stream l_{ur} on the conveyor is decreasing from the auxiliary drive towards the main drive.

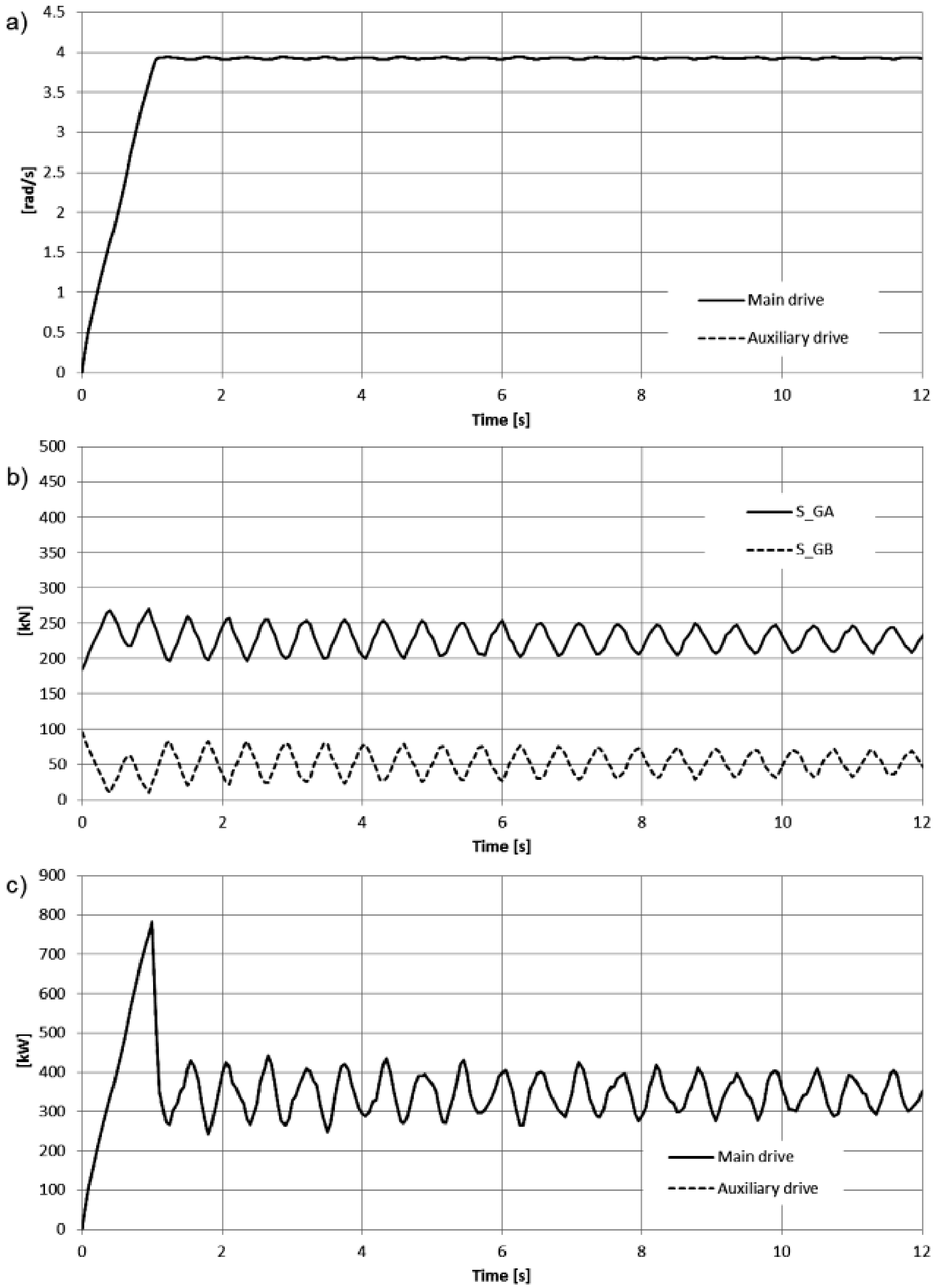

Fig. 4. Start-up and set motion in a conveyor with the length L of 220 m loaded along its entire length with a mined coal stream at a rate of m_u = 160 kg/m for $\dot{x}_B$ = 0 m/s: a) angular velocity of sprocket drums, b) dynamic loads in the chain, c) mechanical power consumed by drives

- The shifting of the auxiliary drive frame is started a result of the ASTEN algorithm's action in the set motion of the conveyor in the eighth second of the simulation.
- The auxiliary drive frame is shifted at the speed rate of $\dot{x}_B$ = 0,05 m/s.

The value of the maximum power consumed by the drives in the set motion fell from 443,1 kW to 332,9 kW (Fig. 5) as a result of unloading the upper branch fully. The drives were loaded uniformly due to the existing state of non-slackening of chains and the lack of load asymmetry of the upper branch with mined coal. A considerable change in the load of the drive motors was a reason for the ASTEN algorithm to operate as a result of which the auxiliary drive frame was displaced into a new position. The following was experienced in the investigated conveyor when the movement of the drive frame was stopped:

- reduction of the maximum dynamic load value in the chain in the place where the chain is unwinding from the chain drum in the auxiliary drive from 103 kN to 57 kN;
- reduction of the maximum dynamic load value in the chain in the place where the chain is running onto the chain drum in the main drive from 221,7 kN to 121,9 kN;
- reduction of the value of maximum power consumed by the conveyor drives from 332,9 kW to 233,6 kW.

The condition of constant chain slackening occurred in the examined face conveyor after loading the upper branch with mined coal at a rate of 40 kg/m along the entire length of the face with the set chain initial tension value of 20 kN. The loading was simulated of the upper branch and the mined coal stream length l_{ur} was increased from the auxiliary drive towards the main drive. It was assumed that during start-up and in the set motion of the conveyor, loading on the upper branch to the fourth second of the simulation would be 40 kg/m, and the mined coal stream length will be equivalent to the conveyor length (L = 220 m). For the simulation time of $t_s \geq 4$ s, the upper branch of the conveyor will be loaded at the length l_{ur} with a stream of mined coal at a rate of 200 kg/m. The operation of the ASTEN algorithm was activated in the 8th second of the simulation.

The start-up time of a conveyor with a fixed auxiliary drive frame after loading the upper branch with mined coal at a rate of 40 kg/m along the entire length was shorter than 1 second. When the loading of the upper branch changed to 200 kg/m at the length of l_{ur} = 73 m, the following changed in the set motion of the conveyor (Fig. 6):

- Growth of the maximum dynamic load value in the chain in the place where the chain is running onto the chain drum in the main drive from 106,2 kN to 147,8 kN;
- Growth of the value of maximum power consumed by the main drive from 307,6 kW to 390,8 kW.
- The maximum value of uncompensated elastic elongation of the chain increased from 0,16 m to 0,25 m (Fig. 7a). Interlink slackening was accumulated in the place where the chain was unwinding from the sprocket drum in the auxiliary drive.

The following maximum values increased after increasing the loading length of the upper branch with mined coal at a rate of 200 kg/m to l_{ur} = 183 m: uncompensated elastic elongation of the chain increased to 0,34 m (Fig. 7b) and the power consumed by the main drive to 542,3 kW (Fig. 8). The ASTEN algorithm was enabled as a result and the auxiliary drive frame was displaced outside the conveyor, which, in turn, reduced the excessive value of elastic elongation of the chain accumulated in the place where the chain is unwinding from a chain drum.

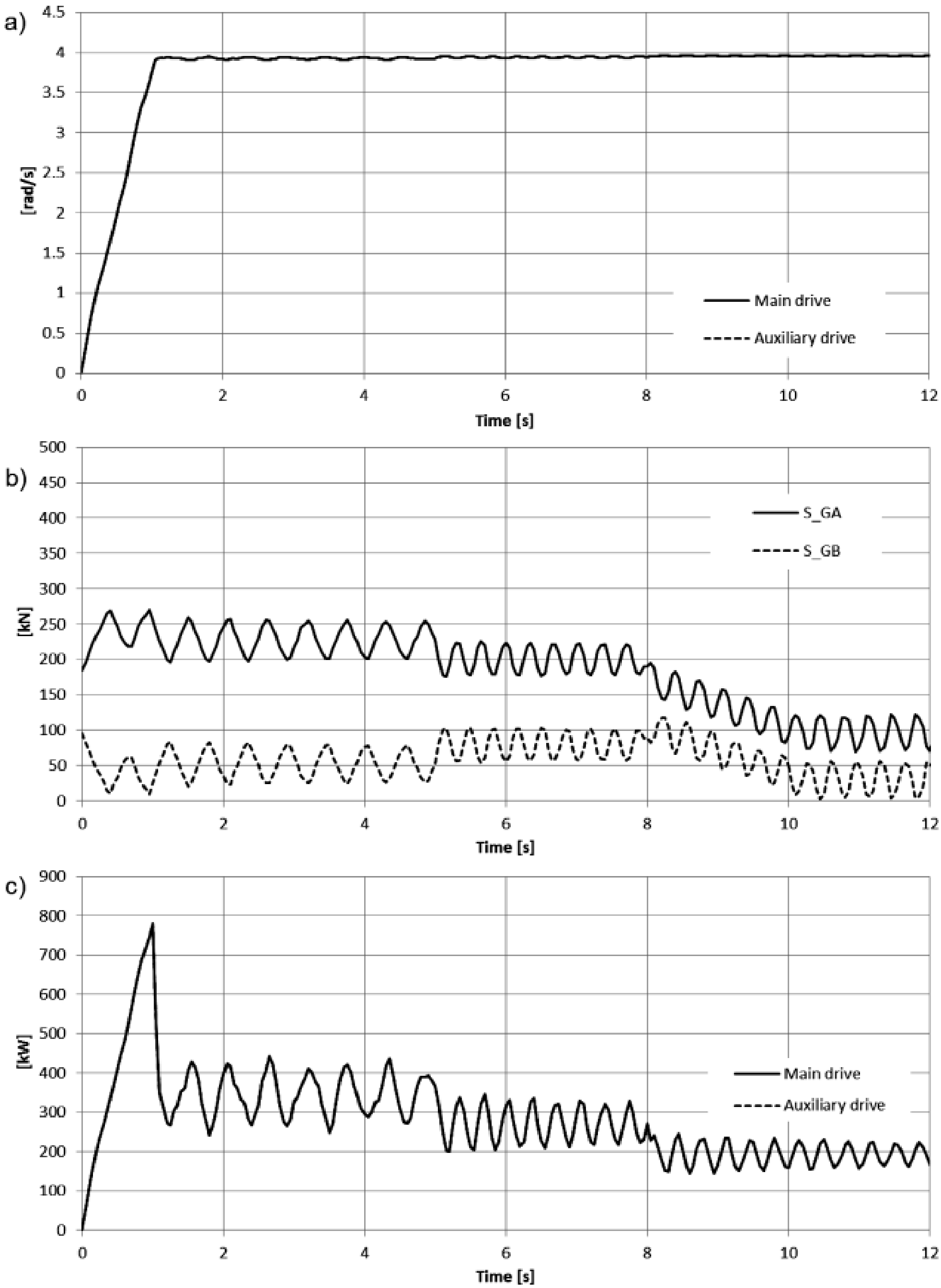

Fig. 5. Start-up and set motion in a conveyor with the length L of 220 m loaded along its entire length with a mined coal stream at a rate of m_u = 160 kg/m at the length of l_{ur} = 0 m, for $\dot{x}_B$ = 0,05 m/s: a) angular velocity of sprocket drums, b) dynamic loads in the chain, c) mechanical power consumed by drives

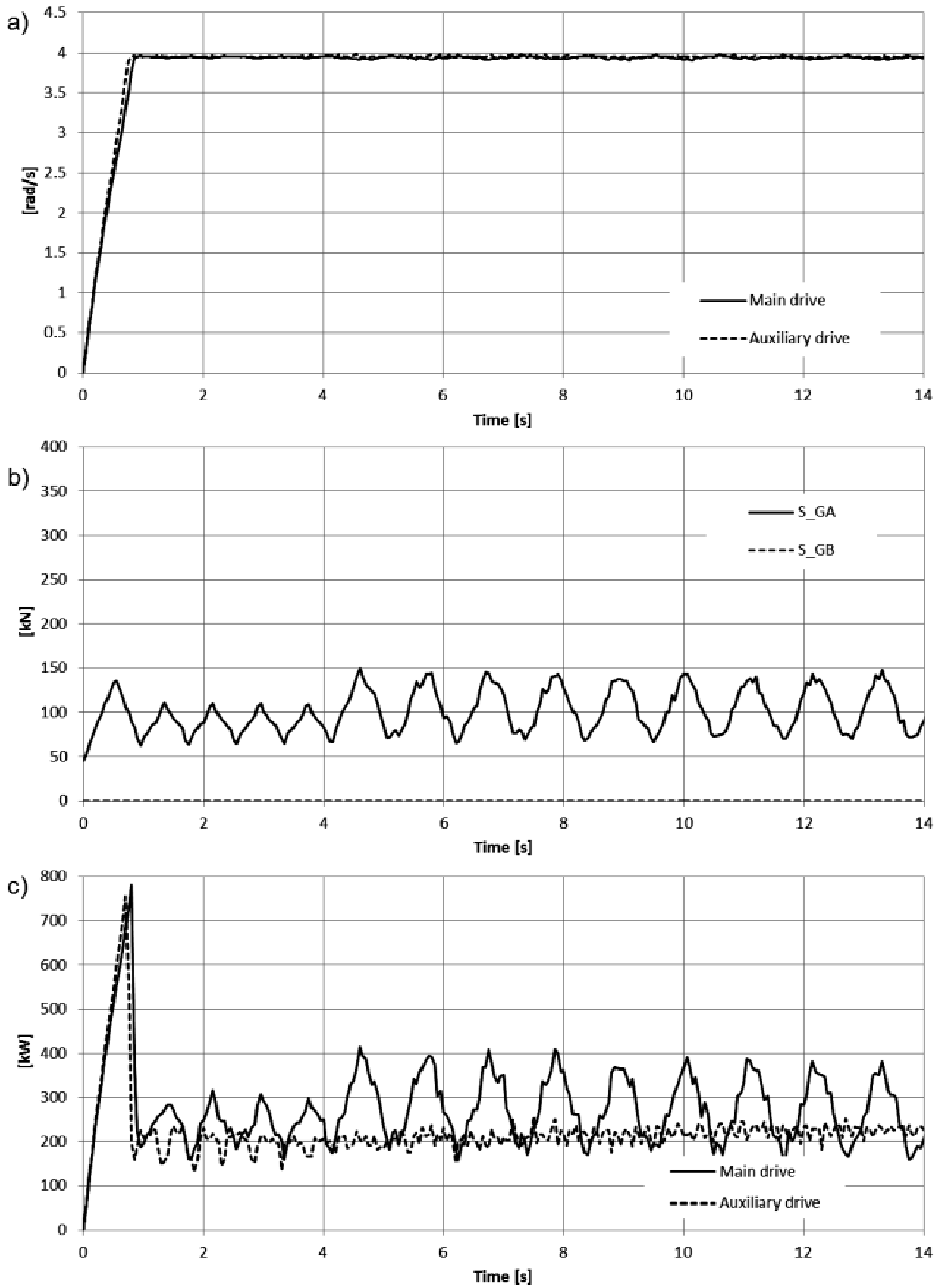

Fig. 6. Changes in the load of the upper branch with mined coal with the length of L = 220 m, l_{ur} = 73 m and $\dot{x}_B$ = 0 m/s: a) angular velocity of sprocket drums, b) dynamic loads in the chain, c) mechanical power consumed by drives

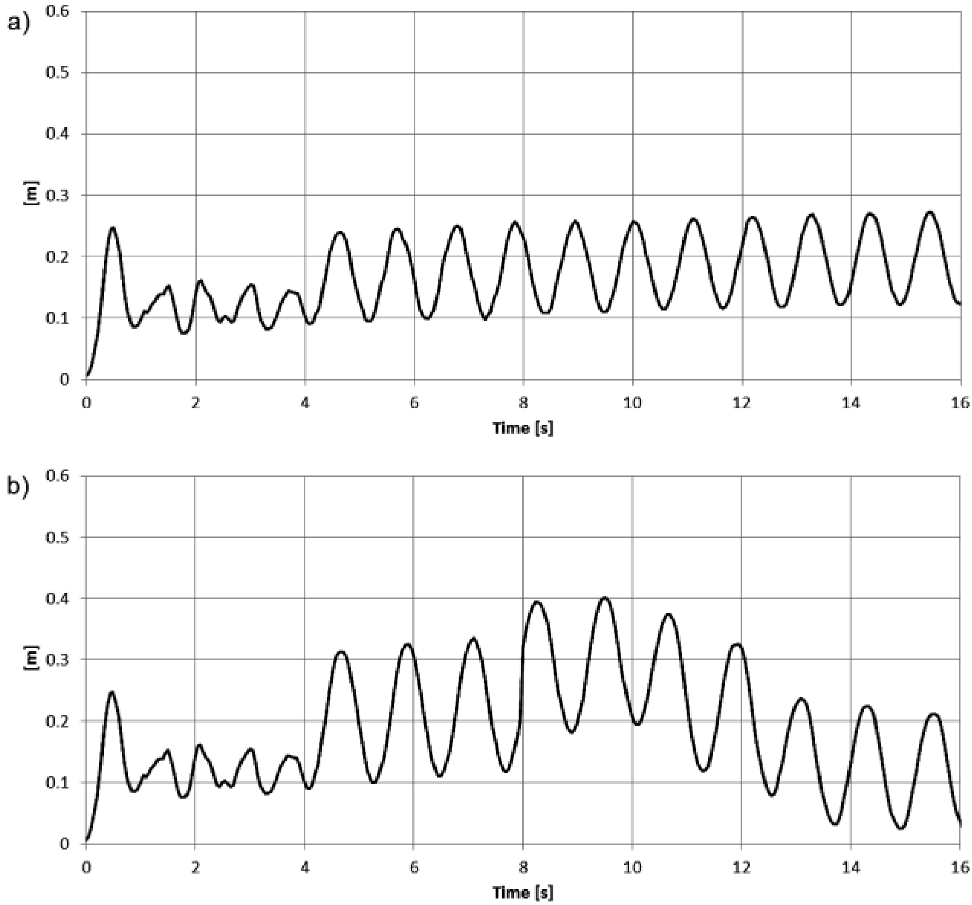

Fig. 7. Uncompensated elastic elongation of the chain in the face conveyor with the length of L = 220 m: a) $\dot{x}_B$ = 0 m/s, l_{ur} = 73 m, b) $\dot{x}_B$ = 0,05 m/s, l_{ur} = 183 m

5. Summary

The computer investigations carried out with an own dynamic model of a face conveyor confirmed the operational efficiency of an innovative algorithm of follow-up tension of scraper chain ASTEN using signals from chain slackening sensors by the main drive, from scrapers position sensors by the auxiliary drive and from current transformers by the both drives. The action of this algorithm causes not only follow-up adjustment of the required initial chain tensioning to the conveyor's operating conditions but also substantial reduction in dynamic loads in the chain and in power consumption of the drives.

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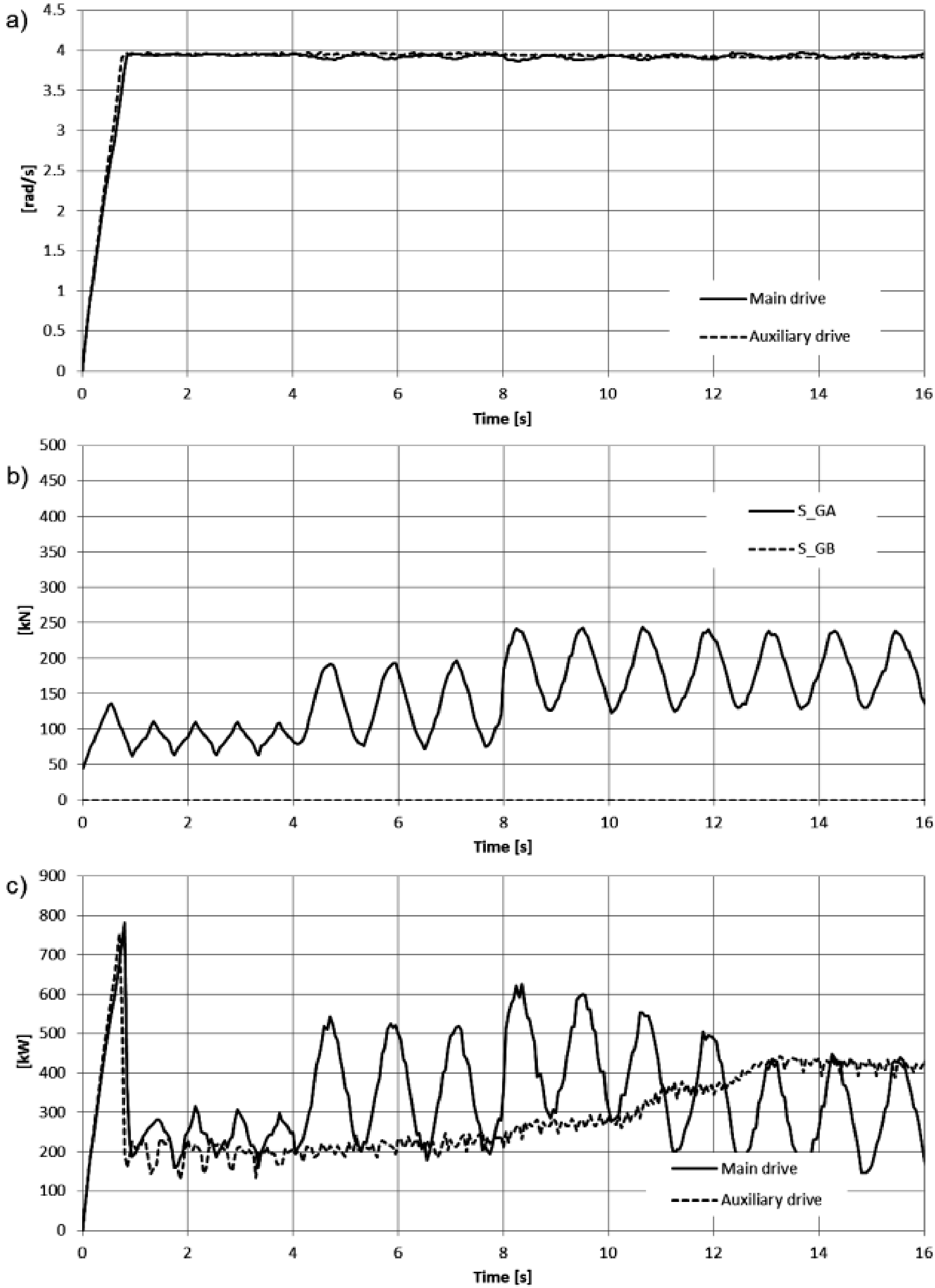

Fig. 8. Influence of changes in the length of the mined coal stream in a conveyor with the length of L = 220 m, for l_{ur} = 183 m as a result of the ASTEN algorithm operation: a) angular velocity of sprocket drums, b) dynamic loads in the chain, c) mechanical power consumed by drives

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