ZESZYTY NAUKOWE POLITECHNIKI ŚLĄSKIEJ 2003
Seria: GÓRNICTWO z. 257 Nr kol. 1599

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EXPLOITATION CUTTING HAULAGE SPEEDS OF A DRUM SHEARER ESTIMATED WITH COMPUTER METHODS

Summary. A mining chain tension member is of essential importance for the process of transportation of run-of-mine material on a coal face. Before making the selection of the AFC and the appropriate link chain it is necessary to calculate the predicted shearer cutting haulage speeds and its output. A special set of procedures has been developed to calculate the work cycle and the real maximum speed of the shearer. The results of many industrial tests have been applied during the development. A set of many important limitations has also been included in the mathematical model of the shearer. This is the first program that allows the prediction of the shearer cutting haulage speeds and output necessary for the selection of the AFC and link chains.

EKSPLOATACYJNE PRĘDKOŚCI URABIANIA KOMBAJNU DWUBĘBNOWEGO WYZNACZONE METODĄ KOMPUTEROWĄ

Streszczenie. W odstawie urobku w ścianie podstawowe znaczenie me właściwy dobór łańcucha zgrzebłowego. Przed doborem łańcucha ogniwowego dła ścianowego przenośnika zgrzebłowego niezbędne jest oszacowanie prędkości urabiania kombajnu i jego wydajności. Specjalny zestaw procedur został opracowany do wyznaczenia czasów pracy załogi w ścianie i obliczenia maksymalnych prędkości urabiania kombajnu. Wyniki wielu badań przemysłowych zostały zastosowane w tych procedurach. Szereg ograniczeń technicznych i ruchowych został włączony w matematyczny model prędkości posuwu kombajnu. Jest to pierwszy model matematyczny wykorzystany do oszacowania prędkości urabiania kombajnu i jego wydajności istotnych w doborze łańcucha do przenośnika zgrzebłowego.

1. Mining standard and flat link chains

The development of highly productive longwall mining technologies requires the application of link chains of the highest quality. Otherwise, it would be impossible. The mining link chains characterized by superior strength are produced in three countries only and namely in England, Germany and Poland. The Capital Group Fasing S.A. is the Polish manufacturer of such chains. The high quality of chains produced is assured due to the application of new materials and novel production technologies and methods of heat treatment. At present, medium link chain, in which the ratio of a pitch p to a rod diameter d is of $3.0 \leq p/d \leq 4.0$, are produced for coal mining applications. Nevertheless, in view of the kinematics of mating of a chain with a sprocket wheel it is recommended to assume $p/d \leq 3.8$. Nominal dimensions of chains being manufactured range from 14x50 mm to 48x152 mm. Their manufacture complies with the standard PN-G-46701:1997 that meets the requirements of pertinent standards DIN 22252 (1999) and ISO 610 (1990E). The factory has commenced lately the production of chains the mechanical properties of which are increased in comparison with those stated in the given standards. They are designed as chains of the class PW9, C-Super and D-3. A conventional mining chain of the class C as per the standard ISO and PN or a Germany chain corresponding to the class 2 as per DIN has standard parameters: its breaking stress is of min. 800 MPa and the ultimate elongation under breaking load is of min. 14%, the elongation under test load of 600 MPa amounts to max. 1.6%. Chains with increased mechanical properties are manufactured in the series of sizes beginning from 18x64 mm and in two versions – as round link chains and flat link ones.

Nominal parameters of strength of mining link chains depending on the given class are specified in the table 1.

Table 1

Strength parameters of round link chains and flat link chains

Chain class acc. to Fasing SA	Stress, MPa			Elongation, % under		Number of cycles in fatigue test in thousands
	operational stress	test stress	breaking stress min.	test stress max	breaking stress min.	
C**	500	600	800	1,6/1,6*	14/11*	70
PW9	560	600	900	1,4/1,6*	17/14*	90
C-Super	560	650	900	1,6/1,6*	18/14*	130
D-3	625	750	1000	1,9/1,6*	16/14*	130

* for flat link chains
** acc. to DIN-22252 and ISO-610

Apart from round link chains there are also flat link chains that are contained in the production program of the Capital Group Fasing S.A. In relation to conventional link chains these chains are characterized in that the vertical links are flattened. A special design of flat link chains results in the increased surface of vertical links and, in consequence, in reduction of specific pressures exerted on conveyor pans, in increased resistance of vertical links to wear as well as facilitates deflection of chain links in pockets of a drive wheel. To meet customer's particular requirements Fasing S.A. offers matched pairs of chain any length indicated. Fasing S.A. offers universal connecting links or of special Rapid type.

Used to connect chain sections, as well as to replace worn out links on the scraper chains conveyors and coal ploughs, the links can operate in both vertical and horizontal positions. Among many advantages the most important is an easy assembly and disassembly of the above links. The connecting links are load tested. A certificate of the mechanical properties testing is supplied. Mechanical properties of this type of connecting links are set up by Fasing S.A. according to the technical requirements. Dimensionally they are in conformity with Polish standard PN.

2. Estimation of work time in the longwall

After determining the number of shifts per day it is necessary to evaluate the crew work time in the longwall T_{ts} [min]. This value can be derived from the difference between the shift time and times needed for reaching the longwall and return to the surface by miners.

The longwall access and return time estimation algorithm describes in simple mathematical formulas individual times related to waiting, riding, getting on and off, walking and job assignment. It has been assumed that the access and return times are equal with the exception of the job assignment time. These times depend on the length of the way and on the speed of the particular means of transport (shaft cage, railway, monorail, belt conveyor, on foot) and also on the waiting, getting on and off times. The sum of these times is the access time T_{dl} and the return to the surface time T_{ds} so $T_d = T_{dl} + T_{ds}$ [min]. The crew work time is the difference between the shift time T_s and the access and return time T_d so $T_{ts} = (T_s - T_d)$ [min]. The real work time during a shift is called $T_{rts} = x \cdot T_{ts}$ [min] where x – percentage of shift work time consumption (i.e. 50%, 70%, 85% or 95%). The value of the x parameter depends on the way the work is organized i.e. if the miners change in place at the longwall x can reach 95%.

The T_d time totals from about 115 to 155 min and depends on level's depth and distance between the longwall and the shaft bottom. So that the crew work time amounts to $T_{ts} = T_s - T_d = 480 - (115 \div 155) = 325 \div 365$ min or more generally – 5 to 6.5 hours. If the T_{ts} time is even shorter, coal mines try to counteract the unwanted situation. For example at Bogdanka coal mine it has been decided that the record-longwall 10/1 with 17000 to 23000 tons of daily output (placed 9 km from the shaft) will work in four working shifts and one maintaining shift per day. Times needed to reach the longwall by workers and to return to the surface amount to about 2x(90 ÷ 100) min, so from 3 to 3.3 hours. During the four shifts effective work time totals about 18 hours. Percentage crew work time consumption for pure winning is from 85 to 90%. In this time about 20 webs are made, that gives the average cutting haulage speed of a drum shearer of 5 to 6 m/min.

According to investigations conducted at Budryk coal mine (drum shearer of the KSW-750E type) parameter x amounted to from 65 to 85%, average – 70%. If the effective work time of shearer in this longwall was $0.7 \cdot T_{ts}$, so the webbing time by bi-directional winning totaled $0.18 \cdot T_{ts}$ and the winning time was $0.52 \cdot T_{ts}$ min.

3. Computer algorithms for calculation of shearer cutting haulage speeds

The main aim of the work was taking advantage of computer aid in optimal estimation of a drum shearer capacity. This capacity has influence on selection of durability and class of mining link chains for AFC. Mining shearers are basic winning machines in the longwall mining technique. Factors characterizing their efficiency are:

- cutting haulage speed,
- web of winning organ,
- power of installed advance and winning motors, which determines winning energy consumption,
- process of loading of run-of-mine on AFC,
- winning technology, including uni- and bi-directional winning.

Only shearers used in medium beds of seam thickness from 1,3 up to 2,1 m and in thick beds (above 2 m) have been taken into consideration in this research. Basic function of a complete longwall system (drum shearer + AFC + mechanized support) is achieving the predicted daily output from the given coal face. Simultaneously to this function the listed below conditions have to be fulfilled: achievement of required safety and work comfort levels, minimization of economic outlays, minimization of the influence exploitation has on the natural environment.

With reference to these conditions machines and devices that make a complete longwall system are characterized by interdependence of construction and motion. This interdependence is a result of complete longwall system functions and longwall geometrical parameters, which take mining and geological conditions into consideration.

Assuming that the following input data is given (fig. 1.): AP – motion parameters and technical data of the shearer; BP – geometrical parameters of the coal longwall; CP – parameters of run-of-mine; DP – corrosion aggressiveness of the longwall environment; EP – drive parameters of AFC; FP – average 24-hours output requirements and number of work shifts; GP – partial walk times for miners reaching the longwall, miners work time per shift – one can use the suggested algorithm of computer aided mining link chain selection for AFC.

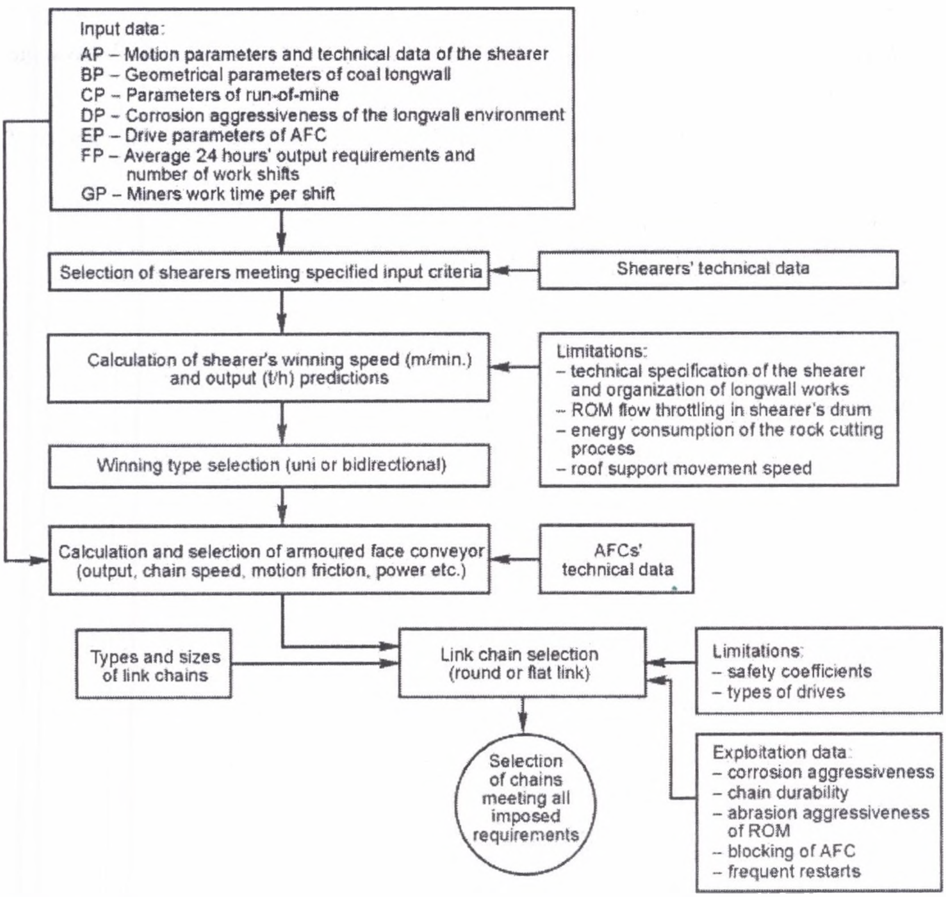

Fig. 1. Very simplified algorithm of the computer selection of mining chains for AFC
Rys. 1. Bardzo uproszczony algorytm doboru łańcucha zgrzebłowego

The procedure of estimation of real work time (T_{rts}) of crew in a longwall is a crucial task of presented algorithm. After calculation of T_{rts} per shift the characteristic cutting haulage speeds of a drum shearer can be estimated. The following cutting haulage speeds of a drum shearer have been used in the algorithm:

- v_{ss} – speed calculated considering the work time per cycle,
- v_{smaxh} – speed calculated considering the maximal hourly output,
- v_{smaxs} – speed calculated considering maximal daily output per work shift,
- v_{sd} – speed calculated considering average daily output.

Each of these speeds can take different values considering different percentage of daily work time consumption per shift. Two mathematical functions describing the dependencies observed in exploitation longwall sets have been used to calculate v_{smaxs}. The first function is a dependence between average daily output (Q_{ld}) and maximal daily output divided by average daily output (Q_{ldmax} / Q_{ld}) (fig. 2).

The second function describes the dependence between the web depth and the number of shearer's cycles (fig. 3).

Another mathematical function has been applied for calculation of v_{smaxh}.

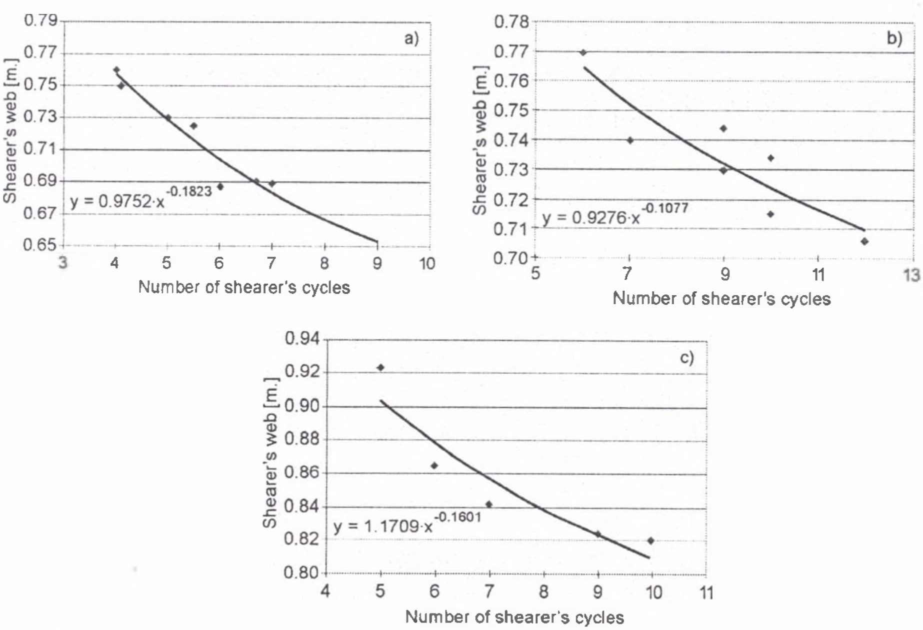

Fig. 2. Maximal daily output Q_{ldmax} to average output Q_{ld} ratio as function of Q_{ld}
Rys. 2. Stosunek maksymalnego dobowego wydobycia Q_{ldmax} do średniego wydobycia Q_{ld} w funkcji Q_{ld}

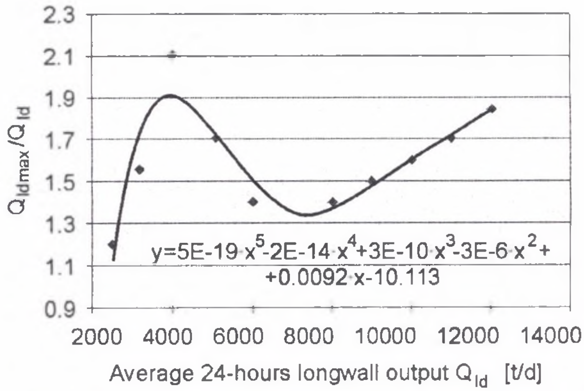

Fig. 3. The shearer web as function of shearer's cycles; a -for web 0,75 m, b - for web 0,85 m, c - for web 0,95 m
Rys. 3. Zbiór w funkcji liczby cykli kombajnu

This function has also been defined basing on several longwall exploitation data (fig. 4). The calculated cutting haulage speeds have to be lower than the boundary values. Shearer's boundary speeds have the following marks: v_{sload}, v_{disu}, v_{sN}, v_{sc} [m/min]. The first of these values comes from assuring a proper loading process of run-of-mine on a scraper chain conveyor by the drum organs (v_{sload}). The second one is a result of time needed to move a single mechanized support section (v_{disu}). The third one is derived from the power of winning organs motors and predicted winning energy consumption (v_{sN}). A special boundary speed is the speed resulting from the shearer's construction (v_{sc}).

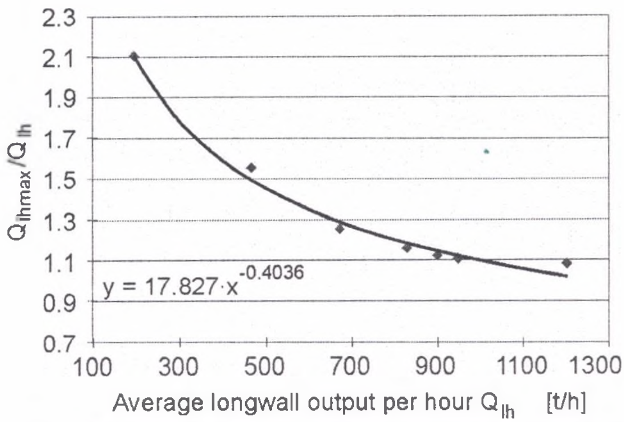

Fig. 4. Maximal hourly output from longwall Q_{lhmax} to average output per hour Q_{lh} ratio as function of Q_{lh}
Rys. 4. Stosunek maksymalnego wydobycia godzinowego ze ściany Q_{lhmax} do średniego wydobycia godzinowego Q_{lh} w funkcji Q_{lh}

This speed is given in technical data of shearer. The calculated values of these speeds for particular example have been presented in chapter 4. A part of the algorithm describing the calculation of shearer advance speed v_{smaxh} has been presented in fig. 5.

Knowing the advance speeds one can calculate appropriate shearer outputs, which influence the AFC selection.

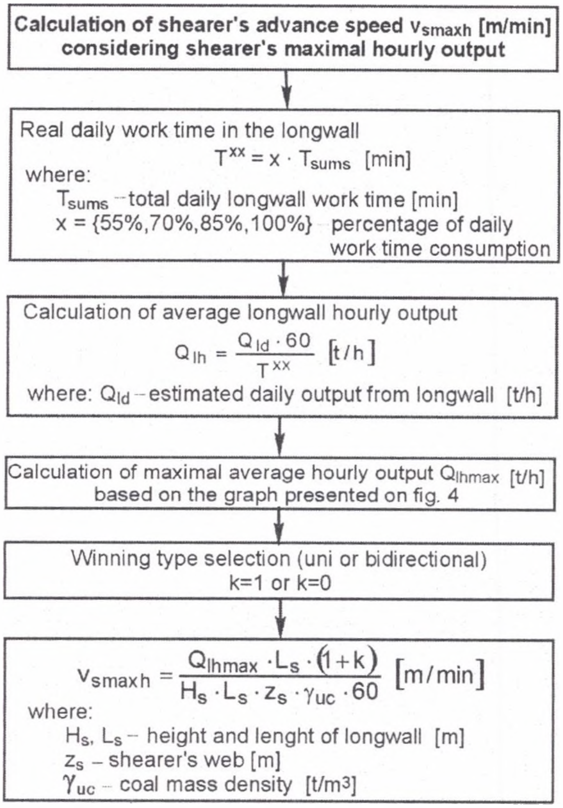

Fig. 5. Fragment of algorithm of calculation of one from set shearer's cutting haulage speeds
Rys. 5. Fragment algorytmu do obliczenia jednej ze zbioru prędkości roboczych kombajnu

4. Example

An example of the calculated shearer cutting haulage speeds for a particular longwall. Longwall data: height H_s = 3.0 m; length L_s = 200 m; longitudinal inclination $\beta_s = 2\div5°$; coal mass density γ_{uc} = 1.4 t/m^3, predicted average daily output Q_{ld} = 4200 t/d, maximal daily output Q_{ldmax} = 8800 t/d, shearer's web z_s = 0.7 m. Technical and organizational times for the longwall: number of work shifts i=3, waiting, up and down hoist ride times 2x30 min, train ride time 2x15 min, time needed to reach the longwall on foot 2x20 min, division of labor time 10 min, so the total additional time T_d = 60+30+40+10=140 min. The effective work time in a longwall is 340 min. Shifting time 20 min. Webbing and maneuver time of shearer in the end of coal face 15 min. Percentage work time consumption x=70%.

Parameters of the shearer: type KGS 750/RW/2D, power supply 1kV, total motor power 2x250 kW + 150 kW, maximal cutting haulage speed 8.5 m/min, drum diameter 2000 mm, drum hub diameter 1000 mm, rasher thickness 40 mm, number of rashers 4, angle of rashers' winding 21°, rotational speed of winning organs 24.6 1/min. Support parameters: type Fazos – 15/31Oz, support width 1.5 m, support unit displacement time 15 s. Results of the calculations have been presented in the table 2. and on the fig. 6.

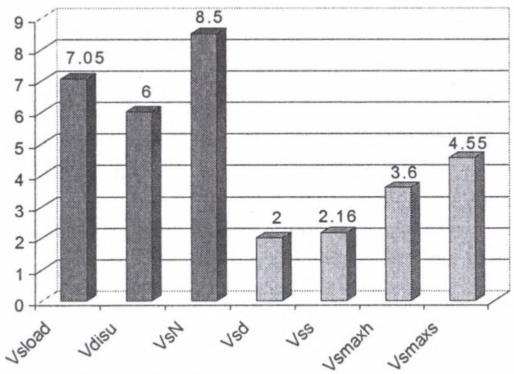

Fig. 6. Calculated shearer cutting haulage speeds – speeds marked as dark pillars correspond with boundary speeds resulting from limits speeds marked as bright pillars correspond with shearer exploitation speeds

Rys. 6. Obliczone prędkości robocze i prędkości graniczne kombajnu bębnowego

Table 2

Calculated shearer's cutting haulage speeds

Shearer's cutting haulage speeds [m/min]							
Boundary speed			Constructional speed	Exploitation speed			
v_{disu}	v_{sload}	v_{sN}	v_{sc}	v_{sd}	v_{ss}	v_{smaxh}	v_{smaxs}
6.0	7.05	8.5	8.5	2.0	2.16	3.6	4.55

5. Final remarks

Before making the selection of the AFC and the appropriate link chain it is necessary to calculate the predicted shearer speed and its output. A special set of procedures has been developed to calculate the work cycle and the real maximum speed of the shearer. The results of many industrial tests have been applied during the development. A set of many important limitations has also been included in the mathematical model of the shearer. This is the first program that allows the prediction of the shearer speed and output necessary for the selection of the AFC and link chains.

Estimations of exploitation cutting haulage speeds conducted for the particular example have been compared to the results gained in praxis. Satisfactory compatibility between these results has been achieved. Important limitations of shearer speed result from loading and displacing of individual shield support.

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Omówienie

W pracy przedstawiono algorytm służący do predykcji eksploatacyjnych prędkości urabiania kombajnu dwubębnowego. Algorytm ten służy także do wyznaczania prędkości granicznych kombajnu wynikających z różnych ograniczeń, a w tym z procesu ładowania urobku, przesuwania sekcji obudowy, energochłonności urabiania i z konstrukcji ciągników kombajnu. Punktem wyjścia jest algorytm określania czasu pracy górników w ścianie i realnego czasu przeznaczonego na urabianie. W pracy rozpatruje się następujące prędkości urabiania kombajnu: v_{ss} – określoną z wykorzystaniem czasu jednego cyklu; v_{smaxh} – określoną z wykorzystaniem maksymalnego wydobycia godzinowego; v_{smaxs} – określoną z wykorzystaniem maksymalnego wydobycia dziennego odniesionego do zmiany wydobywczej; v_{sd} – określoną z wykorzystaniem średniego dziennego wydobycia. W algorytmie wykorzystano wyniki badań eksploatacyjnych kombajnów. Stosując opracowany algorytm przeprowadzono w pracy obliczenia eksploatacyjnych prędkości roboczych kombajnu i prędkości granicznych dla konkretnego przykładu zmechanizowanej ściany węglowej. Otrzymane wyniki porównano z wynikami przemysłowymi i uzyskano zadowalającą zgodność. Wyznaczenie prędkości przewidywanych roboczych kombajnu i jego wydajności stanowi ważny element komputerowej metody doboru łańcucha do ścianowego przenośnika zgrzebłowego.