Modelling of Powered Roof Supports Work

Marcin Michalak

Abstract—Due to the increasing efforts on saving our natural environment a change in the structure of energy resources can be observed - an increasing fraction of a renewable energy sources. In many countries traditional underground coal mining loses its significance but there are still countries, like Poland or Germany, in which the coal based technologies have the greatest fraction in a total energy production. This necessitates to make an effort to limit the costs and negative effects of underground coal mining. The longwall complex is as essential part of the underground coal mining. The safety and the effectiveness of the work is strongly dependent of the diagnostic state of powered roof supports.

The building of a useful and reliable diagnostic system requires a lot of data. As the acquisition of a data of any possible operating conditions it is important to have a possibility to generate a demanded artificial working characteristics. In this paper a new approach of modelling a leg pressure in the single unit of powered roof support. The model is a result of the analysis of a typical working cycles.

Keywords—machine modelling, underground mining, coal mining,

I. INTRODUCTION

FROM the end of the 20th century the increase of production of electric energy from renewable resources can be observed, together with the efforts to limit the influence of traditional energy production technologies. Though in many countries coal – hard and brown (AKA lignite) – remains the main source of energy. For example in Poland in 2012 83% of produced energy was generated from a coal (50% from a hard and 33% from a brown coal) [1] while in Germany the total amount of a coal based energy production was at a level of 45% [2]. This means that problems of coal mining – especially the underground coal mining – still have rather a global than a local meaning.

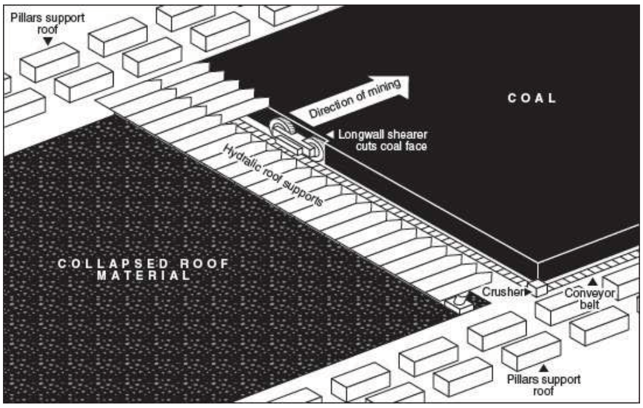

Fig. 1 Longwall scheme [3]

This paper deals with one of the aspects of underground coal mining – the proper work of an essential equipment, which is a powered roof support. The main task of a powered roof support is to assure the safety of work with propping the rock roof after tearing the coal from the rock. The understanding of its work and ability of modelling it gives an opportunity for better machine operating, an increase of a work safety and decrease the cost of coal mining. From the other side building of systems of machines monitoring and diagnosis requires one of two: a real data from machine operated in specified conditions (proper operation, improper operation, faults, accidents and so on) or data prepares by machine model, which can simulate a different ways of a machine operation.

The research presented in the paper are just the first step on the way of building a model of whole powered roof support complex, what is the goal to be achieved in the future.

The paper is organized as follows: it starts from a brief description of a underground coal mining and its most popular realisation – a longwall mining. Then an overview of the powered roof support construction and an analysis of a typical working cycle of powered roof support is presented. Next part describes the developed model with its assumptions and limitations. Then a sample data from the model are presented. The paper ends with some final words and perspectives of further works.

II. UNDERGROUND COAL MINING

Longwall mining is one of the most common way of an underground coal mining. Other methods are continuous mining or room and pillar mining. Longwall is a region in the mine where the hard coal is teared off. The essential part of a longwall mining is a longwall system. It consists of a shearer which tears off the rock, a chain conveyor which transports a teared off material out of a longwall and a set of powered roof supports which props the remaining roof after a shearer move. A scheme of a longwall mining is presented on the Fig. 1. A particular components of a longwall systems are an objective of a monitoring and diagnostic systems and research [7], [8], [10]–[12].

Longwall systems are usually equipped up to several hundreds of single units (called also as sections). Their main task is to protect people and an equipment from the falling rocks. The idea of this protection is presented on Fig. 2. The idea of longwall mining consists of an assumption of an advance of powered supports after each shearer run. It means that a typical cycle of single unit work consists of moments when a section props the roof and a short time when the roof is not supported and a unit shifts towards the direction of the longwall advance.

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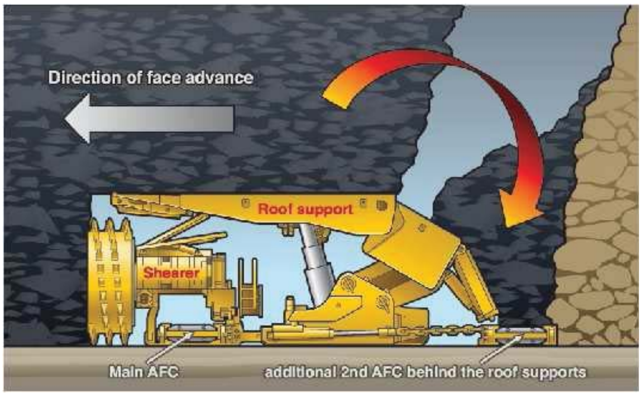

Fig. 2 Longwall profile scheme [4]

III. POWERED ROOF SUPPORTS

The final safety of operations in a coal mine is dependent on several components: a human factor, natural influence, a technical reasons and – of course – from the unexpected circumstances. A technical operating conditions are an object of interest of multiple monitoring systems [6] [9]. The most common monitored signal is the pressure in the leg (legs) of the section, which reflects the real strength of propping the roof. Here the basics of the powered roof support unit structure and its working cycle description are presented.

A. Unit Structure

A single section of a powered roof support consists of one or more hydraulic prop (legs), which holds up an upper part of the section (roof-bar). A section has also and hydraulic shifting system, which is responsible for shifting the unit with the longwall advance simultaneously. Most of the time the unit props the roof, assuring the safety of mining, but after each shearer run it moves to prop the newly bared roof. A single unit is presented on the Fig. 3.

Fig. 3 Single unit of powered roof support [5]

B. Working Cycle

A typical unit working cycle will be presented on the real – 6000 seconds long – observation of the pressure in one of the two-leg unit, shown on the Fig. 4.

Let us start the analysis from the moment in 635th second – we can observe a rapid pressure decrease which lasts around 13 seconds. It preludes the next phase of unit work cycle which is a shifting the whole unit. It is worth to notice that if a pressure decreases to the level of 1.0-1.5 MPa than it means that a roof-bar loses the contact with the roof. It is also observed that the shifting is performed without the full losing roof contact: it is called a ”with contact” shifting and is represented with a several times higher leg pressure. The shifting phase can be localised between 649th and 751st second on the presented time series. The duration of this phase (treading) is usually constant due to the fact that the shearer webs usually the same coal seam thickness.

Next phase - spragging – is an initial, rather fast, leg pressure increase and it is performed as long as the full contact with the roof is again assured (seconds from 752nd to 772nd). After that the slow leg pressure increase is observed.

IV. MODELLING OF A SINGLE WORKING CYCLE

For the purpose of modelling a single powered roof support working cycle was divided into several phases. The decomposition presented in the next section is much more detailed than an overview presented in the previous part of the paper. The result decomposition is a result of an analysis of dozens of sampled time series.

A. Working Cycle Decomposition

As it was presented in the previous section, a typical powered roof support unit working cycle can be divided into several phases. Starting from the moment of the beginning of unit shifting the following phases are named and described as follows:

A) **treading**,
B) **spragging**,
C) **overbuilding**,
D) **pre-treading**,
E) **pressure lowering**.

The first phase – treading – is a short-lasting phase. It usually starts after a roof-bar stops to prop the rocks. An exception of this definition is a treading called as “with contact”. As its name says – the treading has the place in the situation, when the roof-bar still props a rock, but not with the full strength. In the both cases a hydraulic actuator moves the whole section in the direction of a longwall advance. Of course the “with contact” treading requires much more power due to the rock resistance.

From the modelling point of view, the model of this phase should contain the phase duration and starting pressure.

The main task of the second phase – spragging – is to assure an unit to be contacted with the rock again. This phase is shorten than treading. During this phase a pressure in unit legs is increased as long as the roof-bar will start to prop the rock again.

In this modelling approach this phase is represented as the linear pressure increase, so unlike the previous phase model, this part of model requires except the initial pressure level and the phase duration also the speed of the pressure increase.

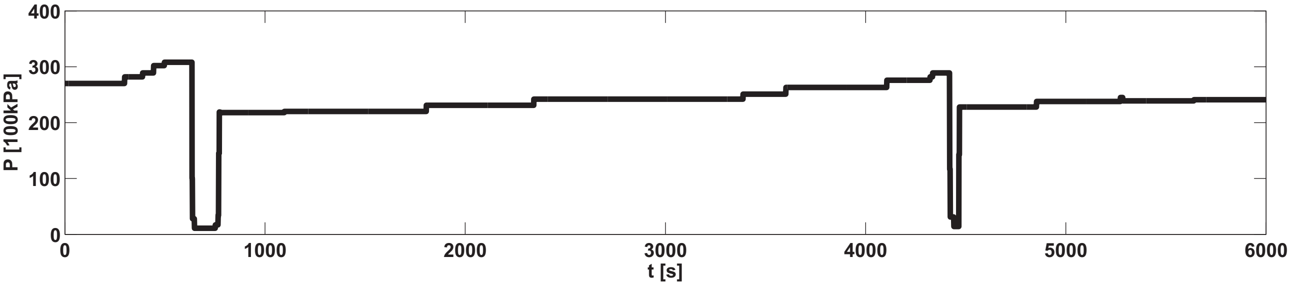

Fig. 4 A real time series of pressure in the unit leg

The third phase – overbuilding – deals with the process of an increasing rock thrust. After a previous phase is finished a fixed unit height is reached. The increasing rock thrust tries to press the unit so the hydraulic system response is a mentioned pressure increase in legs.

The dynamic of the pressure increase is usually linear, but the speed of this increase is much smaller than in the dynamic of the previous phase.

The fourth phase – named pre-treading – also describes the increase of the pressure in legs, but its nature is different. As the shearer approach the specific unit it means that it teared off some of material from the rock. Because the speed of a shearer is greater than the speed of treading – treading phase is longer than the time of tearing of the one unit width of a longwall – some previous sections do not prop the roof. It causes higher load of the specific unit before it will start to tread.

Due to the complicated nature of this effect a several types of a pressure increase should be considered, like linear, exponential and so on. Both the type of increase, its rise and other mentioned values (initial pressure and the phase duration) should became parameters of this phase model.

The analysis of real data leads to the remark that the final phase of a single unit working cycle in the most of observed cases has a form of a binary.

B. A Review of a Real Working Characteristics

Figures presented in this section should help to understand the model construction and the nature of the modelled data. The first one (Fig. 5) presents a comparison a typical treading (left side) and a treading "with contact" (right side).

The data comes from a two-leg sections and a pressure in each leg is presented as a separate series. The unit, which moves with a contact, still has quite high pressure level in the both of legs.

On the Fig. 6 the linear character of a pressure increase during the spragging phase can be observed.

This phase starts at about 780th second and lasts four seconds (on the Fig 4).

The linear nature of the overbuilding phase is clearly visible on the Fig. 4 between 800th and 4000th second and again starting from the 4500th second to the end of the presented sample of the data. It characterises a very slow pressure increase.

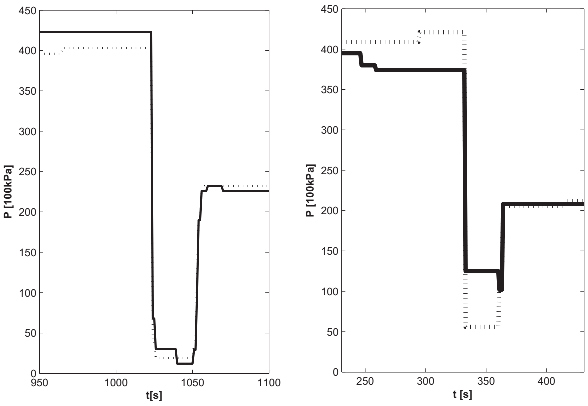

Fig. 5 Pressure visualisation during an unit treading

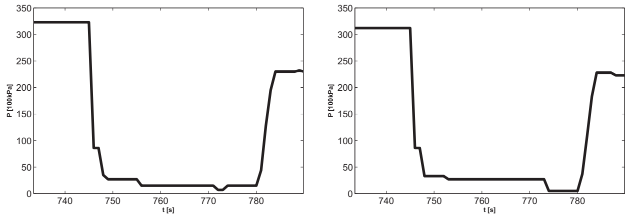

Fig. 6 A linear pressure increase during a spragging

As it was explained in the previous section, shortly before the pressure lowering preceding the treading, a faster increase of the pressure in the leg is observed. The character of this increase and the duration of this phase may vary due to the longwall conditions (a tear off depth, current phases of surrounding units, shearer speed, etc.). Several of them can be described as linear (presented on Fig. 7), exponential (presented on Fig. 8) or arched – representing a quarter of a circle (presented on Fig. 9).

The pressure lowering usually is performed in a single second as it is presented on the Fig. 10. But it also happens that it requires two or three second to reach the demanded level for a treading phase (see on Fig. 11).

C. Model Assumptions and Limitations

From the analysis of real data the mentioned five phases of a single unit working cycle were proposed. For every phase

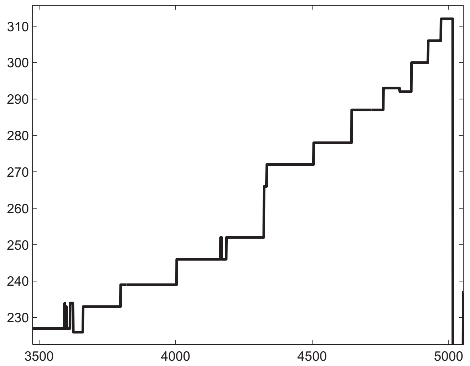

Fig. 7 A linear pressure increase during the pre-treading

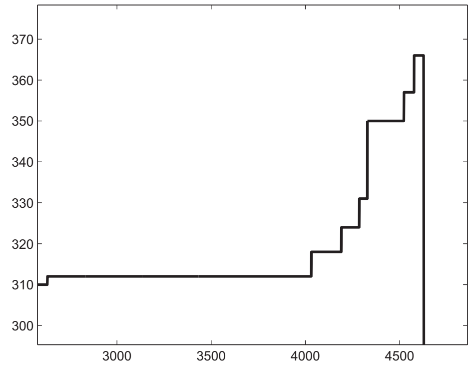

Fig. 8 An exponential pressure increase during the pre-treading

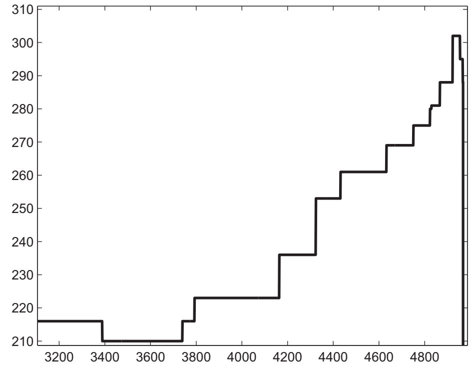

Fig. 9 An arched pressure increase during the pre-treading

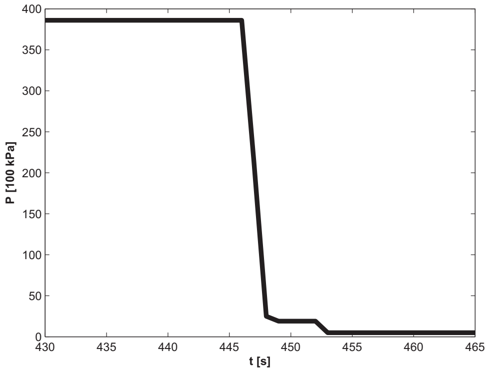

Fig. 10 A complete pressure decrease during the pressure lowering

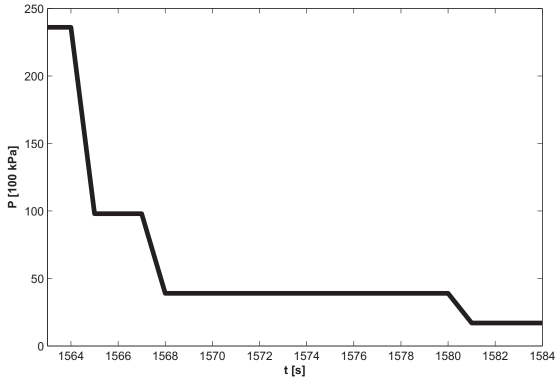

Fig. 11 A gradual pressure decrease during the pressure lowering

also a brief overview of a model, describing this phase, was presented. The model of a first phase is a linear model, but its duration and its level (a low pressure for a typical treading and a high pressure for a treading “with a contact”). Next two models are linear but the slope for the first one is much higher than a second one.

The fourth phase – pre-treading – is characterised by a faster than in accordance with the phase of overbuilding pressure increase. Three possible model of this increase was described in the previous section: a linear, an exponential and arched. Also a squared model can be taken into consideration. The equation of each model, on the domain of $x \in [0; 1]$ and a codomain $y \in [0; 1]$ is presented in Table I. All models are presented on the Fig. 12.

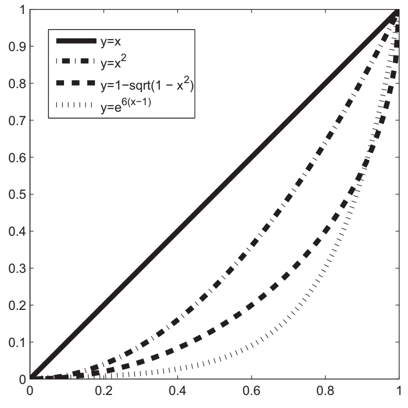

Fig. 12 Possible pressure increase shapes in the fourth phase

Though all models are defined on the normalised domain

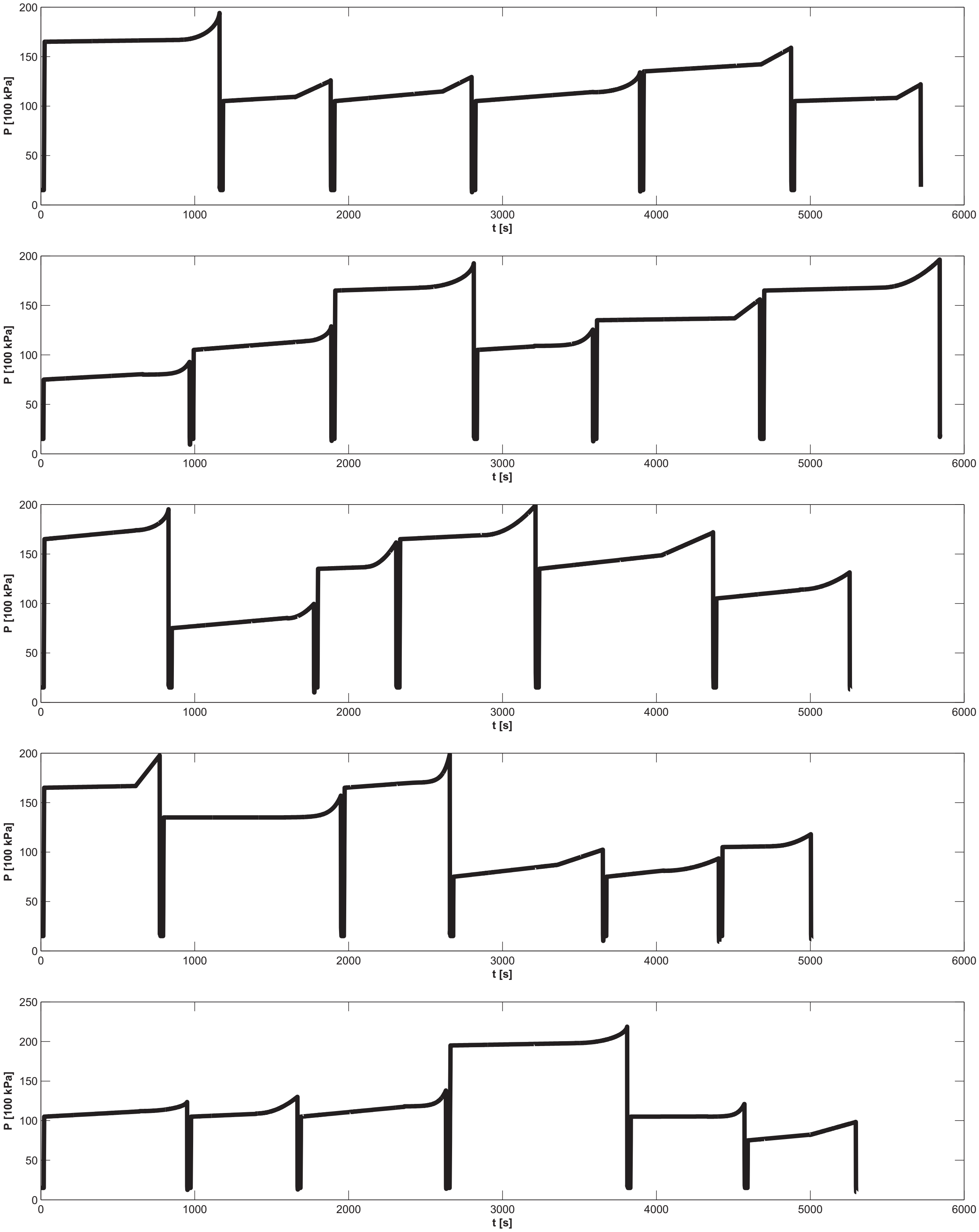

Fig. 13 Leg pressure time series generated by the model

TABLE I
EQUATIONS OF FOUR MODELS OF PRE-TREADING

model	equation
linear	$y = x$
squared	$y = x^2$
exponential	$y = exp(a(x-1))$
arched	$y = 1 - \sqrt{1-x^2}$

and codomain it is not a problem to spread these ranges. If we assume the duration of this phase t and the growth during this phase as ΔP than the addition to the initial level of a pressure, that implies from the demanded model f in the moment t_i is:

$$\Delta P(t_i) = \Delta P \cdot \left(f\left(\frac{t_i}{t}\right)\right)$$

where t_i means the number of seconds of this phase duration.

Presented assumptions help to define the model as the set of parameters. Starting from the selecting the duration of each phase, through their dynamics. A final value of a pressure in the preceding phase becomes an initial value of a pressure in the next phase automatically. Times of phases durations are randomized, similarly as the slopes of lines in second and third phase. The class of the shapes of the pre-treading phase and pressure lowering phase are also randomized.

This decomposed model of a single powered roof support does not input any noise or randomness, understood as the deviation from the specified course of a selected function. In other words - only the parameters of the following models are randomized, not the final values of a model. A model generated leg pressure time series are presented on the Fig. 13.

V. CONCLUSIONS AND FURTHER WORKS

Building a diagnostic models and software requires a lot of data, coming from the monitored device. This is especially difficult for a big and complicated devices to deliver a data from a various ways of operating, including some faults and human mistakes. Delivering a reliable data generator simplifies and speeds up building diagnostic models as it become possible to analyse even very sophisticated deviation from the proper machine operation.

In this paper a simple approach for building a model of a single powered roof support unit was presented. This model reflects all typical phases of the correct work of the device. As it was presented in the comparison in the previous section, modelled data corresponds with the original courses generally.

It must be stressed that the model in its present form does not include a lot of aspects of real disturbances, just to mention the most important like leakage of the hydraulic liquid, correlation between two (three) legs of the same unit, influence of the other units work phases, shearer localisation.

The further works will focus on including a mentioned elements in the model progressively.

ACKNOWLEDGMENT

This work was supported by the European Union from the European Social Fund (grant agreement number: UDA-POKL.04.01.01-106/09).

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