CALCULUS MODELLING FOR DESIGNING RANGING DRUM SHEARER VARIANTS WITH CUTTING SPACE SIMULATION

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Abstract: *A kinematic-geometric calculus modelling of a handling arm mechanism actuated by hydraulic cylinder is derived and presented in this paper. The calculus model leads to an interactive CAD application of studying and design processing several variants of such mechanism. Special emphasis will be placed upon variants of a mechanism used for driving the mobile arm which positions the cutter-loader's ranging drum. The mechanism can also be used in other areas of applied mechanics.*

Key words: *mechanism, calculus model, kinematics, analysis, positioning angle, work space.*

1. Introduction

In this paper, the handling arm - ranging drum mechanism under analysis represents the active working part of a mining cutter-loader, as it is shown in Figure 1.

The handling and ranging removal φ of the cutting drum of D_t diameter is realised by the ranging arm 4 of l_b length. This can be positioned at a certain cutting height H (φ), $H \leq H_{\max}$, within a specific angular interval of arm rotation, $\varphi \subset [\varphi]$.

The positioning movement of the ranging arm, $\varphi = \varphi(s)$, is developed by means of hydraulic cylinders acting as driving elements (Figures 2 and 3), with linear actuating s motion as input quantity in the handling system, as shown in Figure 3.

This mobile arm subassembly is jointed to the machine central body by a swivel connection, which allows of the arm rotation $\varphi(s)$. The H_0 height (Figure 1) is a machine specification of a certain cutter-loader.

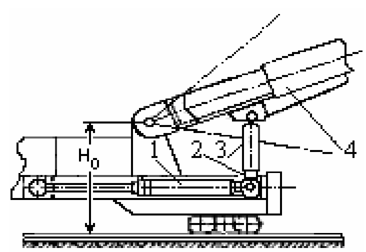

Fig. 1. *Constructive schema*

Further on, a new variant of kinematic calculus modelling is proposed, which is an adequate analytical support and approach to an interactive CAD application for the optimal design of such mechanical systems.

With this aim in view, the calculus modelling is meant to facilitate the interactive design of the analysed system, which has been achieved by using it successfully as a CAD tool via MATHCAD application.

The interactivity is especially facilitated by the graphical visualisation, which offers

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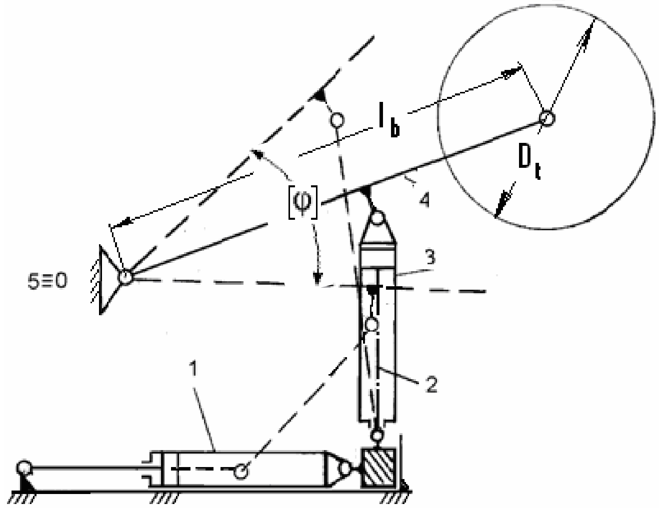


Fig. 2. *Kinematic schema*

a fast assessment of the results. Also, it makes it possible to simulate the work space of cutting ranging drum, on the face height.

2. Variants of the Analysed System

Two variants of handling arm - ranging drum mechanism have been analysed: the basic existing one with a rigid connecting rod, and a proposed new one having a driving rod. The driving rod consists of a second hydraulic cylinder introduced in the system, as shown in Figure 2.

Structurally, the basic variant [2-4] is a mono-mobile four-link mechanism with $\varphi = \varphi(s)$, while the proposed new variant is a bi-mobile five-link mechanism (Figures 2 and 3) having $\varphi = \varphi(s, s_2)$. Noteworthy is the fact that the two command inputs s, s_2 work sequentially in two phases. During the first phase, s is acting until the second hydraulic cylinder reaches a vertical position (Figures 2 and 3, $\psi = 90^{\circ}$). In the second phase, s_2 is driving the mobile arm until the cutting drum is positioned to the face height $H_{\max}(s, s_2)$.

3. Calculus Modelling

A kinematic-geometric modelling of the driving mechanism (version presented) is proposed in Figure 3.

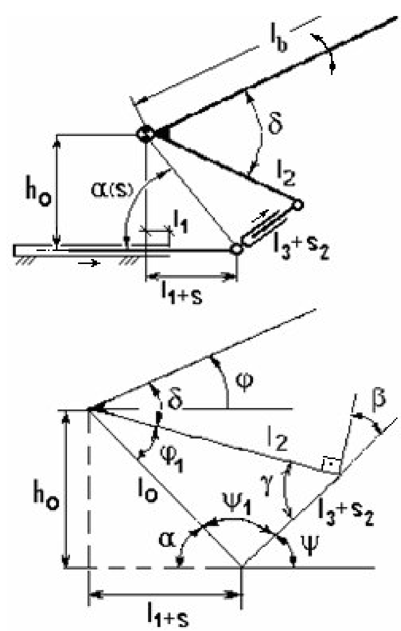


Fig. 3. *Kinematic-geometric modelling*

The simplicity and efficiency of this modelling is based on the kinematic triangular contour, formed by two sides of constant length, l_1 and l_2 (as constructive dimensions) and the side of the variable length l_0 - for the first phase of working - and l_3+s_2 - for the second one. According to this, the handling arm position is given by $\varphi = \varphi(s)$ and $\varphi = \varphi(s_2)$, respectively, where s and s_2 are sequential command inputs, and δ is a specific constructive parameter.

The angles φ_1, Ψ_1 and the transmission angle $\gamma = \gamma(s)$ are auxiliary calculus quantities.

These angles can be calculated directly by the cosine theorem, as internal angles defining the triangular configurations of the driving mechanism's mobile contour, as shown in Figure 3.

For the same configuration, a right-angled triangle is constantly defined by the sides h_0, l_0 and s. This right-angled triangle allows it to define the variable angular quantity $\alpha = \alpha(s, h_0)$.

The position angle φ and the oscillating angle $\Psi \leq 90^o$ are both variable: $\Psi = \Psi(s)$, which is in correlation with $\varphi = \varphi(s)$, for $s \leq s_{max}$. Considering these calculus modelling specifications and with respect to the geometric configuration in Figure 3, the functional quantities φ and Ψ can be expressed in terms of the following basic formulas [1]:

$$\varphi = \varphi_1 + \delta - \alpha; \quad \Psi = \pi - (\Psi_1 + \alpha). \qquad (1)$$

Similarly, the cutting height H - the operating coordinate of the machine - can be expressed in function form:

$$H = H(\varphi(s, s_2)) \leq H_{max} \Leftrightarrow s \leq s_{max}, \qquad (2)$$

and is directly influenced by the constructive parameters l_b - the arm length and D_t - the drum diameter (Figure 2).

Based on (1) and (2), using the cosine theorem and other mathematical formulas and models, the functional expressions and quantities of the calculus procedure can be well defined.

Given this calculus modelling and based on the realistic specifications in this practical field, calculations have been performed by means of a MATHCAD application.

The main sections of this type of application are presented in the calculus appendix shown below.

CALCULUS APPENDIX (*MATHCAD APPLICATION*)

1. Calculus Data and Formulas Classic Mono-Mobile System Variant: (s_2 = 0) – $H = H(\varphi(s))$

$h_0 := 1310 \qquad l_2 := 1600 \qquad l_b := 4100 \qquad D_t := 2000 \qquad l_1 := 200$

$\delta := 17 \cdot \frac{\pi}{180} \qquad l_3 := 1310 \qquad H_0 := 2000$

$l_0(s) := \sqrt{(l_1 + s)^2 + h_0^2} \qquad \alpha(s) := \operatorname{atan}\left[\frac{(l_1 + s)}{h_0}\right]$

$\varphi_1(s) := \operatorname{acos}\left[\frac{\left(l_0(s)^2 + l_2^2 - l_3^2\right)}{2 \cdot l_0(s) \cdot l_2}\right] \qquad \varphi(s) := \left[\left(\varphi_1(s) + \alpha(s)\right) + \delta - \frac{\pi}{2}\right]$

$$\psi_1(s) := \operatorname{asin}\left(l_2 \cdot \frac{\sin(\varphi_1(s))}{l_3}\right) \qquad \psi(s) := \frac{\pi}{2} - (\psi_1(s) - \alpha(s))$$

$$\beta(s) := \frac{\pi}{2} - (\psi(s) - \varphi(s) + \delta)$$

$$s := 0, 100 .. 1400 \qquad s_b := 0, 100 .. 1000 \qquad \theta := 0, \frac{\pi}{12} .. 2\cdot\pi$$

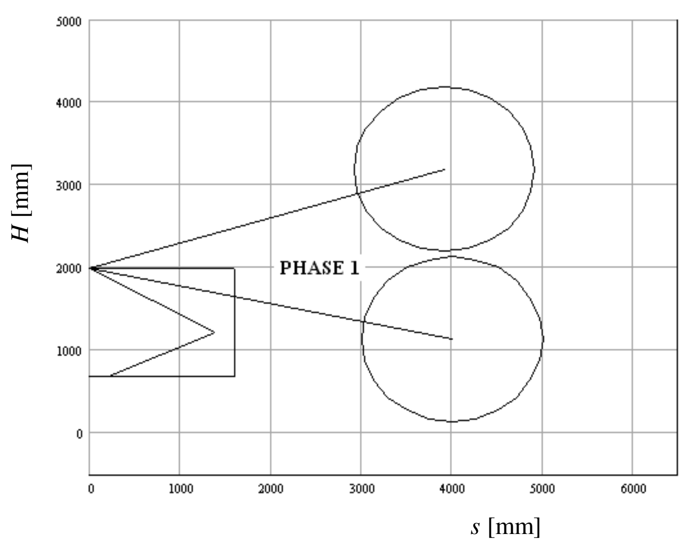
$$W(s) := \begin{bmatrix} l_b\cdot\cos(\varphi(s)) & H_0 + l_b\cdot\sin(\varphi(s)) \\ 0 & H_0 \\ l_2\cdot\cos(\varphi(s) - \delta) & H_0 + l_2\cdot\sin(\varphi(s) - \delta) \end{bmatrix}$$

$$H_{max}(s) := W(s)_{0,1} + \frac{D_t}{2} \qquad H_{min}(s) := W(s)_{0,1} - \frac{D_t}{2}$$

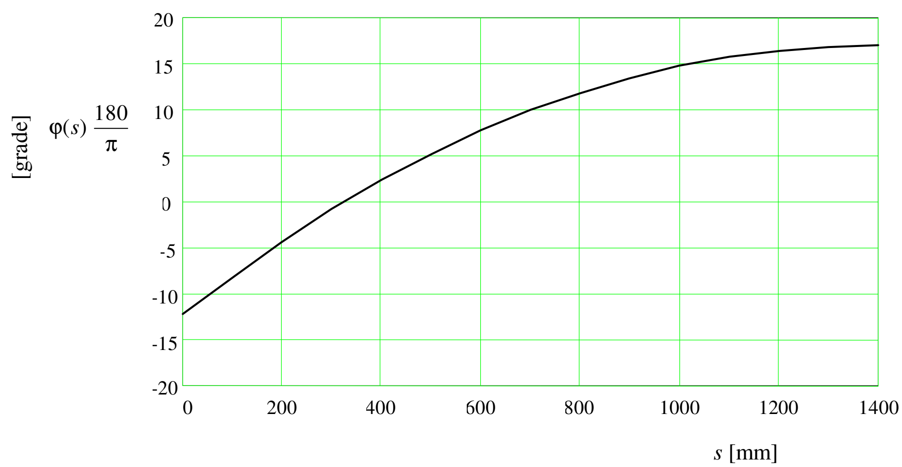
$$V(s) := \begin{bmatrix} 0 & H_0 - h_0 \\ l_1 + s & H_0 - h_0 \\ s + l_3\cdot\cos(\psi(s)) + l_1 & l_3\cdot\sin(\psi(s)) + H_0 - h_0 \end{bmatrix}$$

$$T_x(s,\theta) := l_b\cdot\cos(\varphi(s)) + \frac{D_t}{2}\cdot\cos(\theta) \qquad T_y(s,\theta) := H_0 + l_b\cdot\sin(\varphi(s)) + \frac{D_t}{2}\cdot\sin(\theta)$$

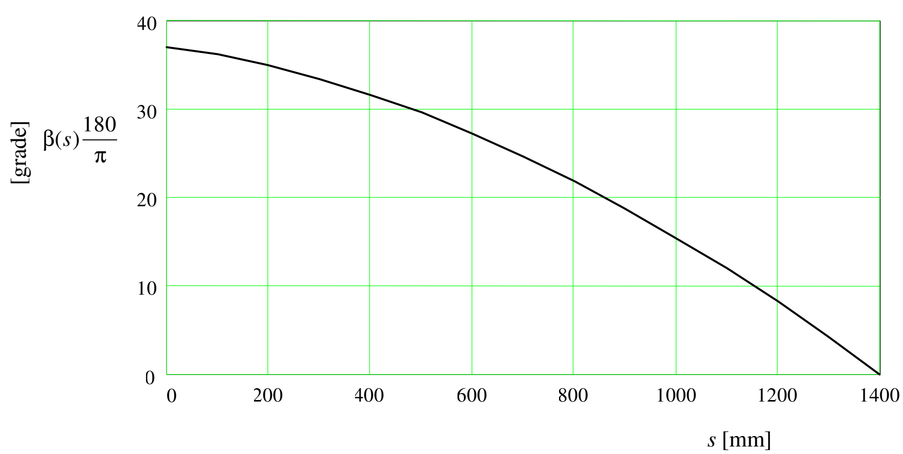
2. The Mono-Mobile Driving System in Extreme Cutting Positions of the First Phase of Driving: *H* = *H*(*s*)



• DIAGRAM $\varphi = \varphi(s)$



• DIAGRAM $\beta = \beta(s)$



3. Calculus Data and Formulas Proposed Variant – Bi-Mobile Driving System: $H = H(\varphi(s,\ s_2))$

$h_0 := 1310 \qquad l_2 := 1600 \qquad l_b := 4100 \qquad D_t := 2000 \qquad l_1 := 200$

$H_0 := 2000 \qquad \delta := 17 \cdot \frac{\pi}{180}$

$l_3(s_2) := 1310 + s_2 \qquad l_0(s) := \sqrt{(l_1 + s)^2 + h_0^{\ 2}} \qquad \alpha(s) := \operatorname{atan}\left[\frac{(l_1 + s)}{h_0}\right]$

$$\varphi_1(s,s_2) := \mathrm{acos}\left[\frac{\left(l_0(s)^2 + l_2^{\,2} - l_3(s_2)^2\right)}{2\cdot l_0(s)\cdot l_2}\right]$$

$$\varphi(s,s_2) := \left[\left(\varphi_1(s,s_2) + \alpha(s)\right) + \delta - \frac{\pi}{2}\right]$$

$$\psi_1(s,s_2) := \mathrm{asin}\left(l_2\cdot\frac{\sin\left(\varphi_1(s,s_2)\right)}{l_3(s_2)}\right) \qquad \psi(s,s_2) := \frac{\pi}{2} - \left(\psi_1(s,s_2) - \alpha(s)\right)$$

$$\beta(s,s_2) := \frac{\pi}{2} - \left(\psi(s,s_2) - \varphi(s,s_2) + \delta\right)$$

$$s := 0, 100..\ 1400 \qquad s_2 := 0, 100..\ 1000 \qquad \theta := 0, \frac{\pi}{12}..\ 2\cdot\pi$$

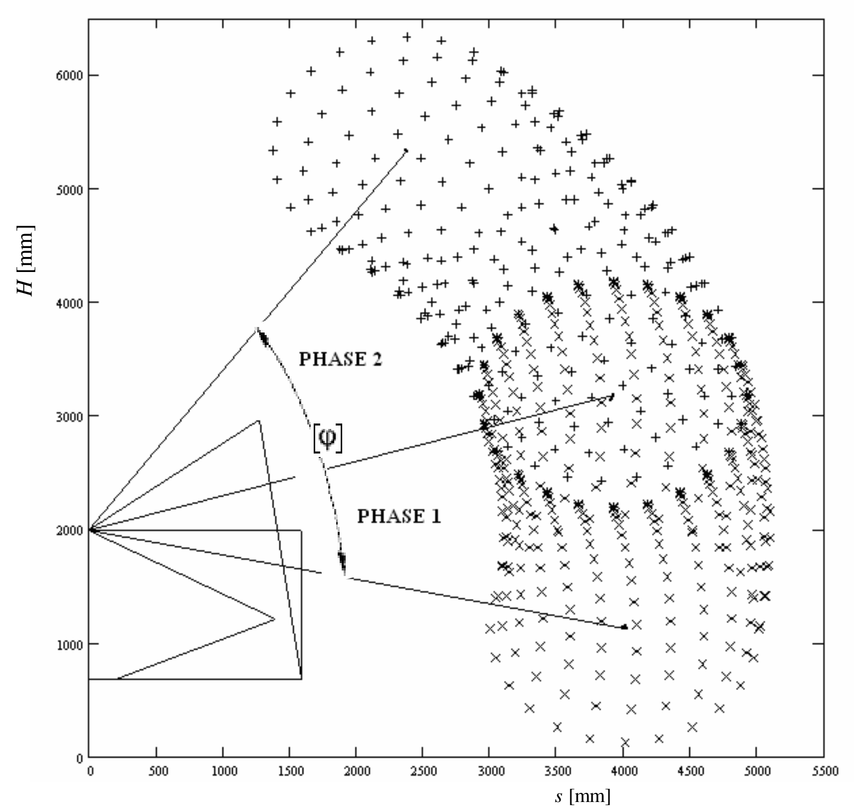
$$W(s,s_2) := \begin{bmatrix} l_b\cdot\cos\left(\varphi(s,s_2)\right) & H_0 + l_b\cdot\sin\left(\varphi(s,s_2)\right) \\ 0 & H_0 \\ l_2\cdot\cos\left(\varphi(s,s_2) - \delta\right) & H_0 + l_2\cdot\sin\left(\varphi(s,s_2) - \delta\right) \end{bmatrix}$$

$$V(s,s_2) := \begin{bmatrix} 0 & H_0 - h_0 \\ l_1 + s & H_0 - h_0 \\ s + l_3(s_2)\cdot\cos\left(\psi(s,s_2)\right) + l_1 & l_3(s_2)\cdot\sin\left(\psi(s,s_2)\right) + H_0 - h_0 \end{bmatrix}$$

$$T_x(s,\theta,s_2) := l_b\cdot\cos\left(\varphi(s,s_2)\right) + \frac{D_t}{2}\cdot\cos(\theta)$$

$$T_y(s,\theta,s_2) := H_0 + l_b\cdot\sin\left(\varphi(s,s_2)\right) + \frac{D_t}{2}\cdot\sin(\theta)$$

4. Cutting Space of the Ranging Drum Bi-Mobile System - The Three Working Positions, Marking the Two Phases of Acting: $H = H(s, s_2)$, Corresponding to the Entire Arm Rotation Interval [φ]



4. Conclusions

According to the facts already mentioned and to the calculus in the appendix, this newly proposed modelling allows of an iterative and interactive CAD procedure.

Besides, this interactivity is efficiently realised by using the visualisation of the geometric configurations of the ranging cutting drum system on the coal face, at different cutting height values. Thus, a direct and rapid evaluation of the system's design variants is facilitated, in relation to the variations of functional kinematic parameters.

On the other hand, this interactive method leads to the valorisation of a certain competence and experience of a well-qualified designer, which allows of the study and comparison of different variants of such a mining machine system.

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