Automatically Optimised Billet Cutting in the Laminating Flux

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Abstract. The automatic billet cutting system is formed of: (1) monitoring and measuring elements located in the laminating line: infrared photocells, pulse transducers, current relays; (2) programmable logic controller **PLC** integrated in a control desk **CD** in the control station (specific software: LOGICMASTER); (3) panel view with touch-screen **OP**, located in the same **CD (**specific software: WINCONFIGURATION); (4) IBM compatible **PC**, located in the control room (specific software: CIMPLICITY); (5) actuators: adjustable converters for the actuation of the motor driving the shears and the measuring roller **MR**1; (6) controlled equipment: rotary shears and measuring roller with their associated devices, roll stands. The automatic billet cutting system performs the following automatic operations:
- Through the monitoring and measuring elements and through the **PLC,** it calculates and measures the laminate cross section, laminate length when entering and exiting the roll stands; laminate speed when exiting the stand; billet cutting length; length of remaining laminate. Also, it commands and controls the circular motions of the shears.
- The system allows the operator's intervention in the laminating process (from the **OP**).
- It monitors the laminated batch on the **PC** (number, length, cross section of laminates and billets, etc.) .

Keywords: automation, cutting, software, laminate.

1. DESCRIPTION OF THE CONTINUOUS FLUX CUTTING LINE

1.1. Structure and technical characteristics of the cutting line machines

The laminating line in the cutting area (Fig. 2) consists of the following main machines (listed in reverse order of the laminating and cutting process): ***shears*** (with driving gear and associated motors); ***measuring roller*** $\mathbf{MR_1}$; ***stands*** $\mathbf{k_{10},\ldots k_7,\ k_6}$ **;** ***photocells*** $\mathbf{B_7},\ldots\mathbf{B_0}$ along the line between the area of discharge of the cut laminate and $\mathbf{k_6}$; ***pulse transducers*** $\mathbf{G_1}$, $\mathbf{G_4}$, $\mathbf{G_3}$, $\mathbf{G_2}$ from: $\mathbf{MR_1}$**,** shears**,** $\mathbf{k_7}$ and $\mathbf{k_6}$**.**

The optimised cutting control system consists of: ***in-line elements*** ($\mathbf{G_1}\ldots\mathbf{G_4}$: speed, lengths, angles; $\mathbf{B_0}\ldots\mathbf{B_7}$; tachogenerators; current relays $\mathbf{F_1}$, $\mathbf{F_2}$); ***control desk CD*** mounted in the control station and including: ***PLC*** which controls the cutting process based on its application program; ***operator panel OP***, serially connected to the **PLC**, which displays process data and sends to the **PLC** the operator's commands keyed in from the **OP** display; ***non-stabilized continuous voltage supply*** U_1 for feeding the line elements and the **PLC** inputs and outputs; ***IBM PC*** for cutting process monitoring.

1.2. Cutting process

1.2.1. Operating modes

The control of the rotary shears, by means of the optimising system, can be made in four operating modes, selectable from the operator's panel **OP**:

1. ***TEST*** *mode:* for testing the machines with no laminate in the line. In this mode, it is possible to test both the shears control mode (with adjustment from the **OP** of the repetition time interval) and the line elements.

2. Cutting mode with ***PHOTOCELL*** B_7*:* In this mode, cutting is performed automatically according to the signal indicating the presence of the laminate, generated by photocell $\mathbf{B_7}$, and to the time set by the operator from the **OP,** in the **PLC**. This mode is used in case of failure of the measuring transducers and line photocells.

*3. **AUTOMATIC** cutting mode:* In this mode, cutting is performed automatically (including head and tail cutting and remainder cutting on condition that it is not in the range of 1…3 m), controlled by the **PLC**, based on the indications supplied by the line elements, the lengths being preset by the operator from the **OP**, all operations being performed in real time.

*4. **OPTIMISED** cutting mode:* In this mode, cutting is performed automatically optimised, being controlled by the **PLC** based on the information supplied by the pulse transducers and photocells in the line, the cutting lengths being calculated automatically by the **PLC** according to the range preset from the **OP** with "zero" remainder condition, displayed on the **OP** and accepted by the operator from the **CD**, all operations being performed in real time.

1.2.2. Operating mode

The laminate moves at a constant speed in the range of 1...4.5m/s, during which time the shears will have to cut a preset length in the range of 5,400...16,000 mm (with 0,06% accuracy). The cutting length is selected by the operator from the **OP**. The gear driving the shears knives has a circular motion during which the knives remain in vertical position. **The operating cycle of the rotary shears knives** is the following, for a complete rotation of 360^0:

- the shears starts from the *idle position* (0^0) and **accelerates** the motion up to an angle automatically determined by the **PLC** depending on the laminated section; this point is located before the contact point between the shears and the laminate; the *accelerated motion* is controlled in the ignitron converter through speed controller and acceleration controller at an induced current of approx. 2780 A; the *speed of the knives driving motors (peripheral speed of the knives) and the acceleration time* $\mathbf{t_a}$ are calculated automatically by the **PLC** and they modify automatically depending on the *speed correction* v_c given by the measuring roller $\mathbf{MR_1}$ based on the formulas given below; the purpose of the determination in advance of the peripheral speed of rotation of the shears knives is to determine the time corresponding to the **advance length** of the laminate which is added to the time corresponding to the imposed cutting length for the exact determination of the cutting point when the cutting current is released:

- advance length: $L_{av}= a*(k/\cos\alpha_t)*v_e^2 + b*(\cos\alpha_t/k)$ **(1)**
- acceleration time: $t_a=2*a*(k/ \cos\alpha_t)*v_e$ **(2)**
- acceleration angle: $\alpha_a=[(1/2)*\omega*t_a]*(180^0/\pi);\ \omega=(2*\pi*n)/60$ **(3)**
  $\alpha_a=3*n*t_a$ **(4)**; $\alpha_a=6*a*(30/\pi*R)*(k/ \cos\alpha_t)^2*v_e^2$ **(5)**
- driving motor speed: $n= i*(30/\pi*R)* (k/ \cos\alpha_t)*v_e$ **(6)**
- acceleration constant **a**: $a=[(\Sigma GD^2*i)/(2*375*M_b)]*(30/\pi*R)$ **(7)**
- constant speed time: $t_c= b*(\cos\alpha_t/k)/v_e$ **(8)**
- constant speed angle: $\alpha_c=180^0- \alpha_a$ **(9)**
- cutting angle: $\alpha_t= \arccos(1-c/R*\sqrt{2})=28^0\ldots38^0$ **(10)**

where: **c**–side of the square of the cross section of the laminate; $\mathbf{v_e=1\ldots4.5}$m/s–laminate speed when exiting mill train 2 (stand $\mathbf{k_{10}}$); $\mathbf{R, i, M_b, \Sigma GD^2, k}$-parameters of the shears

- when reaching the *cutting point* the converter receives a *cutting current setpoint* $\mathbf{I_t}$ of approx. 4000 A during the interval of laminate cutting ($\pm14^0\ldots\pm19^0$ around the value of 180^0); the speed of the knives must be equal to the laminate displacement speed $\mathbf{v_e}$ or a little higher (by 2%); after cutting, the *speed and acceleration controllers* and the knife is driven at *constant speed* with a current of 2780 A over the angular distance $180^0+\alpha_t/2$;
- when reaching the point of $180^0+\alpha_t/2$ the *braking* of the knives starts until reaching the zero position, ($345^0...0^0...15^0$).

2. DESCRIPTION OF THE OPTIMISATION SYSTEM

2.1. Shears cutting cycle

The figure below (Fig. 1) shows the diagram of the motion of the lower and upper knives of the rotary shears over a complete rotation of 360^0 (which represents a cutting cycle). The shears knives wait in the idle position (A and A', antipodal to the cutting point T). The motors driving the shears are stopped. The shears operate in start-stop mode. A cutting cycle involves the travel in direct trigonometrical direction (upper knife), in reverse direction respectively (lower knife) over the circular path and the return to the idle position. In order to define the motion, the following values shall be considered: **angle** α for *the momentary knife position;* **idle position angle** $\alpha_0=0^0$; **performed cutting angle** $\alpha=180^0$; **cutting angle** α_t

corresponding to the arc CT, C being *the point where the knife touches the material*; **acceleration angle α_a** corresponding to the arc AB, B being *the point where the necessary peripheral speed v_e is reached*; **laminating speed v_e** with which the laminate comes out of the last stand $\mathbf{k_{10}}$ from the mill train; **angle α_c** of travel at *constant speed* corresponding to the arc BT. The values corresponding to the arcs are approximately: AB=26^0…154^0, AT=180^0, AD=208^0…218^0. Point D corresponds to the start of the knives braking.

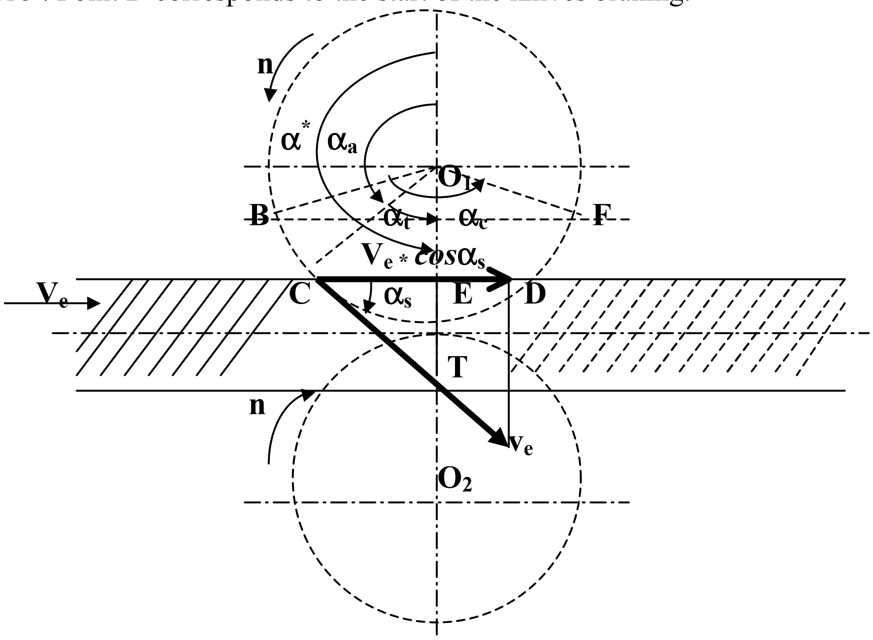

Fig. 1

2.2. Cutting sequence control

The cutting control consists in commands generated by the **PLC** (through the output) to the converter supplying the shears driving motors simultaneously with the creation and transmission of the speed setpoint $\mathbf{n}^*$ in acceleration mode (through analog output). The moment of generation of the cutting command is established by means of the two counters: of head and remainder monitoring and of cutting length.

The counters in the PLC receive, through the pulse counting input, the pulses from the counter $\mathbf{G_4}$, located on the axle of the measuring roller $\mathbf{MR_1}$. Between the cutting command and the actual performance of the cutting, the material moves over a distance – ***advance length L_{av}*** – given by the relation (1). As the cutting command must precede the passing of the cutting length given by the relation above, the moment when the counter commands the idle position monitoring block is not the reaching of zero but the reaching of the constant term “b”. *The head counter* is forced to the value set from the **OP** when photocell $\mathbf{B_5}$ is excited. The loaded value also contains the distance between photocell $\mathbf{B_5}$ and the closed position of the knives. The length counter is loaded with the value set from the OP when the cutting signal is received. Photocell $\mathbf{B_5}$ commands the *raising of the measuring roller* $\mathbf{MR_1}$, which is made with a time delay from the moment of its excitation (*material presence)* as well as its *lowering* when the material disappears. A separate counter counts the pulses from the measuring roller $\mathbf{MR_1}$ between two cuttings. In this way it can be seen if the billet was cut at the correct length. The measured length (real) of the cut billet is displayed on the OP. The same counter also performs the supervision of the tail simulating the presence of the material even after the tail has disappeared from the photocell range and inhibiting the tail cutting for a remaining length of 1 to 3 m.

2.3. Control of the OPTIMISED cutting system

Due to the fact that the length varies from one ingot to another within very wide limits, the last piece resulted has a length in the range 0…$\mathbf{L_{imposed}}$, non-controlled. Although $\mathbf{L_{imposed}}$ can vary (for certain sections and destinations within the limits of a range), however the uncertainty regarding the total length resulted after lamination makes it impossible to eliminate this drawback, which leads to a high percentage of material losses. The *exit length* $\mathbf{L_e}$ cannot be measured in advance because the cutting is made during lamination. There resulted the necessity

of a control system focused on fulfilling a ***null remainder*** criteria. The cutting optimisation system estimates the value of the *exit length* $\mathbf{L_e}$, adopts and presets an *imposed value* for *the optimum cutting length* which satisfies the optimum criteria: $\mathbf{L_{min} < L_{opt} < L_{max}}$ **(11)**
Remainder **(R)=0.** If **N** is the total number of cut billets, then: $\mathbf{N*L_{min}<L_e<N*L_{max}}$;
$\mathbf{0<(L_e-N*L_{min})/N<L_{max}-L_{min}}$ from which: $\mathbf{N>(L_e-N*L_{min})/(L_{max}-L_{min})=R/\Delta L}$ **(12)**
where: $\mathbf{0<R< L_{min}}$ **(13)**

The least favourable case for fulfilling (12) is when **R** is maximum, that is $\mathbf{R>L_{min}}$, the range ΔL being given for a certain destination $\mathbf{N> L_{min} / \Delta L}$ **(14)**

The higher $\mathbf{L_{min}}$ and the lower **ΔL**, the better can be satisfied the optimum criteria (1) only for longer ingots. For shorter ingots, a loosening of the criteria was foreseen, namely:
$\mathbf{R>6{,}000mm;\ L_{min} < L_{opt}< L_{max}}$ **(15)**

The calculation principle for achieving (1), (5) respectively by the control system is the following: The estimation of the total length of the laminate when exiting the mill train $\mathbf{L_e}$ is made on the basis of the constant volume principle: $\mathbf{L_e * v_i = L_i * v_e = ct.}$ **(16)**
where: $\mathbf{L_i}$ = length when entering the stand; $\mathbf{L_e}$ = length when exiting the stand; $\mathbf{v_i}$ = speed of laminate entering the stand; $\mathbf{v_e}$ = speed of laminate exiting the stand $\mathbf{L_e = L_i \times v_e / v_i}$ **(17)**
Therefore, knowing $\mathbf{L_i}$ and the ratio of the speeds $\mathbf{v_e / v_i}$ (o constant), there results the exit length $\mathbf{L_e}$. Once $\mathbf{L_e}$ is known, $\mathbf{L_Q}$ is calculated (*actual length* which is introduced into the optimisation calculation, after deducting the head and tail cuttings and the fixed lengths already cut when the value $\mathbf{L_{opt}}$ is available). The maximum number of optimised pieces is calculated:
$\mathbf{N_{pcs} = L_Q / L_{min}}$ (full part) **(18)**
The optimum length is: $\mathbf{L_{opt}= L_{min}+(L_Q - N_{pcs} * L_{min}) / N_{pcs}}$ **(19)**

In order to achieve the optimised cutting based on the above-presented criteria, considering the calculations, the operations and the decisions being complex, there resulted the necessity to use a microcomputer (PLC). For the purpose of optimising the cutting, the PLC performs in real time the following operations:

a) Input length measuring $\mathbf{L_i}$

The input length $\mathbf{L_i}$, with which the laminate enters stand $\mathbf{k_7}$, is measured by the PLC by means of the rotary pulse transducer $\mathbf{G_2}$, mounted on the axle of the driving motor of stand $\mathbf{k_6}$. *The measuring correction* γ *of the input length* $\mathbf{L_{ik}}$ (corresponding to the laminate number **k** of the batch of laminates exiting stand $\mathbf{k_6}$) is performed by means of a photocell $\mathbf{B_0}$ mounted after stand $\mathbf{k_6}$. The correction factor γ (mm/pulse) of the laminate length (or of the rotating speed of stand $\mathbf{k_6}$) is calculated as being the ratio between a known length $\mathbf{L_1}$ and the number of pulses $\mathbf{N_{L1}}$ from stand $\mathbf{k_6}$ corresponding to length $\mathbf{L_1}$. The input length measuring is made with 4 photocells $\mathbf{B_1 \ldots B_4}$ mounted at known distances $\mathbf{L_3}$ (or $\mathbf{L_4}$ or $\mathbf{L_5}$ or $\mathbf{L_6}$) from the axle of the cylinder of stand $\mathbf{k_7}$, on the roller track (in front of stand 7V/$\mathbf{k_7}$). The measuring principle is the following:

To the known distance $\mathbf{L}_{3,4,5,6}$ is added the distance measured from the top of the ingot tail to the photocell, from the moment when the material is caught in stand $\mathbf{k_7}$.
$\mathbf{L}_{tail} = \lambda \cdot \mathbf{N}_{tail}$ there follows: $\mathbf{L}_i = L_{tail} + \mathbf{L}_{3,4,5,6}$. $\mathbf{L}_{3,4,5,6}$ is automatically selected by the PLC from the list of the four distances $\mathbf{L}_3 \ldots \mathbf{L}_6$, depending on the photocell which commanded the counter $\mathbf{N}_{tail}$ to stop (the first from $\mathbf{B}_1,\ldots\mathbf{B}_4$ de-excited after $\mathbf{F_2}$ = "1"). For this, the number of the respective photocell is stored in a register. The register is erased at the next counting. *The measuring correction* λ *of the input speed* $\mathbf{v_{k2}}$ into stand $\mathbf{k_7}$ is made by means of a photocell $\mathbf{B}_1,\ldots\mathbf{B}_4$. The correction factor λ (mm/pulse) is calculated as being the ratio between a known length $\mathbf{L}_{3,4,5,6}$ and the number of pulses corresponding to this length. The calculation formula used is: $\mathbf{\lambda_k=[L_{3,4,5,6}/N_{kB1,2,3,4}] \times i}$ **(20)**
$\mathbf{N_{kB1,2,3,4}}$ – is the number of pulses from the pulse transducer $\mathbf{G_3/k_7}$ corresponding to length $\mathbf{L_{3,4,5,6}}$ (the sequence of counting these pulses, performed by a counting register in the PLC, is started by the de-activation of the first photocell of the four: $\mathbf{B_{1,\ldots 4}}$ and it is stopped by the de-activation of current relay $\mathbf{F_2}$).

The input speed $\mathbf{v_{ik}}$ with which the laminate number **k** enters stand $\mathbf{k_7}$ is calculated with the formula: $\mathbf{V_{ik}= L_{ik} / T_{ik}}$ [mm/s] **(21)**
where: $\mathbf{L_{ik}= N_{ik} \times \lambda_{k-1}}$ [mm] - input speed of current laminate no. **k** entering stand $\mathbf{k_7}$; $\mathbf{N_{ik}}$-

number of pulses from pulse transducer **G_3/k_7** corresponding to the total length **L_{ik}** of the current laminate **k**; **λ_{k-1}**-length correction for previous laminate; **T_{ik}**-time when pulses are counted **N_{ik}**. There results: $v_{ik}=(N_{ik}\times\lambda_{k-1})/T_{ik}\times 1000xi$ [m/s] **(22)**

b) v_e / v_i speed ratio measuring

The ratio between the exit speed **v_e** from stand **k_{10}** and the input speed **v_i** in stand **k_7** is made by means of two counters **G_4/MR1**, **G_3/k_7** respectively from the **PLC** pulse counting block. During the same time interval, **G_3** counts the pulses from stand **k_7** and **G_4** counts the pulses from the measuring roller of the shears **MR_1**. Calculating the ratio of the two numbers we obtain a value of the speed ratio. Practically, the moment of starting the measurement was selected, the moment of the head cutting. For this, we have conditions **$B_5 = 1$** (+24V signal = "roller lifting" introduced via the input in the digital input block from the PLC) and **SCHNITT = 1** (+24V signal ="closed shears" introduced via the input in the pulse counting block from the PLC). It stops after **G_4** has counted a fixed number of pulses **N_{kMR1}** which, once reached, detected with a coincidence circuit, stops opreşte **G_3**. Then: $v_e / v_i=(N_{kMR1}*\nu_k) / (N_{ik}*\lambda_{k-1})$ **(23)**

The above formula is deduced from the condition of "constant volume" during lamination, namely the volume of the laminate entering stand **k_7** (the first of the train **$k_7 \ldots k_{10}$**) is equal to the volume of the laminate exiting stand **k_{10}**: $V_{ik7}=V_{ek10}$ or $L_i\times s_i = L_e\times s_e$ or, during the same time unit **t**, what enters **k_7** (section **s_i**, speed **v_i**) must exit **k_{10}** (section **s_e**, speed **v_e**):

$L_i / v_i = L_e / v_e$ or $v_e\times L_i = v_i\times L_e$ or $v_e / v_i = L_e/L_i$ **(24)**

The correction factor **ν_k** of the measuring roller **MR_1** (for the current laminate with number **k**, except for the first laminate going into cutting) is calculated as a ratio between the fixed distance **L_{11}** (distance between photocell **B_6** and the shears in closed position, i.e. cutting performed) and the number of pulses counted by the **PLC** register corresponding to distance **L_{11}**: $\nu_k=L_6/N_{kL6}$ [mm/pulse] **(25)**

Based on this information as well as on the data received from the **OP** of the shears ($L_{imposed}$, $L_{head\ cutting}$, section, shears on "optimised") and from the MR_1 frequency correction counter ($N_{correction}$), the **PLC** performs the necessary calculations, makes decisions and supplies: (L_{opt}, put on optimised, N_{pcs}, billet COUNTER, ingot number, remainder, shears correction command, correction sign). These are viewed on the operator panel **OP** at the control desk **CD** in the control station.

c) Data display.

Certain data processed by the **PLC** are displayed on the **OP** screen at the **CD**. The displayed screens contain a certain number of data under numerical or graphic form. The display is of "touch screen" type, allowing modification of some displayed parameters. These modifications can also be made from the five multi-functional keys of the **OP**.

3. APPLICATION

The automatic system presented above, is built and applied by IPA SA at SIDERURGICA SA durring of year 2001. The **PLC** is GE Fanuc 90-30 equipped with 1 processor module, 2 high speed counters modules, 1 analog inputs and 2 analog outputs modules, 1 digital inputs and 1 digital outputs modules. The applicated softwares are LOGICMASTER for **PLC**, WINCONFIGURATION 3.2 for **PO** and CIMPLICITY for **PC**. The system can be applied in instalation requiring precision in cutting. The equipment complies with the international requirements regarding automation equipment and with ISO 9000 and ISO 9001 norms. The implementation of this system can result in significant savings in lamination material and power supply, shorter laminate cutting time, comfort in equipment operation, decreased failure rate.

4. REFFERENCES

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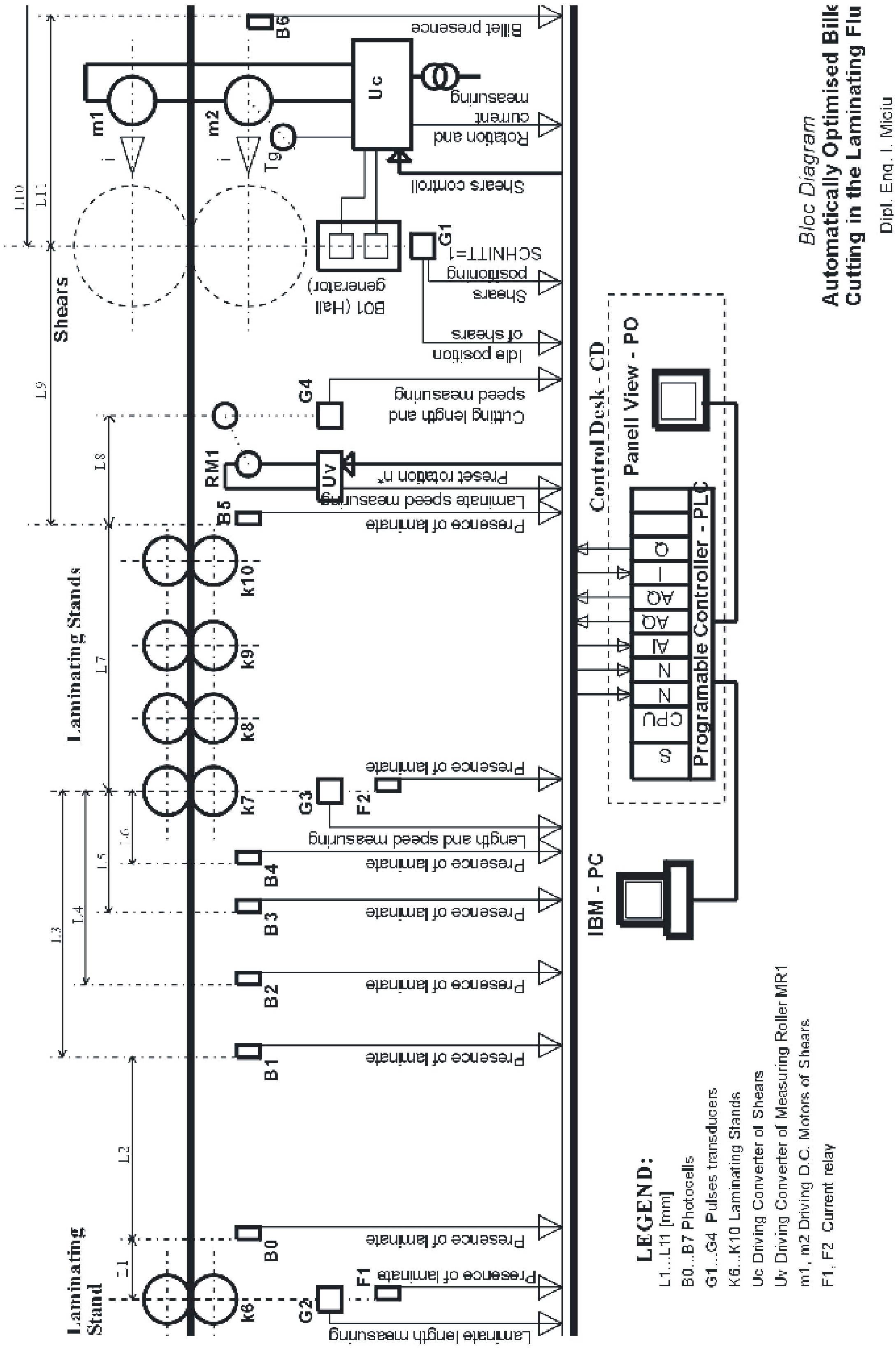
Bloc Diagram
Automatically Optimised Bille
Cutting in the Laminating Flu
Dipl. Eng. I. Miciu
Laminating Stand
Laminating Stands
Shears
k6
k7
k8
k9
k10
m1
m2
Uc
Uv
RM1
Tg
B0
B1
B2
B3
B4
B5
B6
G1
G2
G3
G4
F1
F2
L1
L2
L3
L4
L5
L6
L7
L8
L9
L10
L11
Billet presence
Rotation and current measuring
Shears controll
SCHNITT=1
Shears positioning
B01 (Hall generator)
Idle position of shears
Cutting length and speed measuring
Preset rotation n*
Laminate speed measuring
Presence of laminate
Length and speed measuring
Laminate length measuring
Control Desk - CD
Panell View - PO
Programable Controller - PLC
S
CPU
IN
IN
AI
AQ
AQ
I
O
IBM - PC
LEGEND:
L1...L11 [mm]
B0...B7 Photocells
G1...G4 Pulses transducers
K6...K10 Laminating Stands
Uc Driving Converter of Shears
Uv Driving Converter of Measuring Roller MR1
m1, m2 Driving D.C. Motors of Shears
F1, F2 Current relay

Fig. 2