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(54) **A METHOD FOR THE CONTROL OF A GROUNDWOOD PULPING PROCESS**

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PROCEDE DE COMMANDE D'UNE OPERATION DE REDUCTION DE BOIS EN PATE MECANIQUE

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Description

[0001] The present invention relates to a method for the control of a groundwood pulping process in order to achieve an optimal value for both the drainability of the pulp and for another characteristic of the pulp, preferably for the tearing resistance of the pulp.

[0002] In controlling the pulp grinding process one object is usually to have a constant drainability value or freeness (CF) of the pulp. The control is for instance made so that the wood supply pressure is kept constant, whereby the wood supply rate is allowed to vary. Alternatively the wood supply rate can be kept constant and the supply pressure is allowed to vary.

[0003] When only the CF value of the pulp is used as the measured variable to control the process this of course has a disadvantage in that the CF value will not provide all information about the other quality properties of the pulp, which can be characterised by many measured quantities, such as tearing resistance and tensile strength, light-scattering and opacity.

[0004] The Finnish patent FI 70438 proposes a method to control a groundwood pulp process with the aid of a new quantity, the plasticity of the wood, as the control parameter. A desired pulp property is obtained at a given (constant) peripheral speed of the grinding stone when the supply pressure and the wood supply rate is selected so that during otherwise constant operating conditions (constant wood quality, constant peripheral speed and sharpness of the grinding stone) a plasticity value is obtained.

[0005] From tests which are partly published and which are summarised below, it is known that at a constant freeness it is possible to improve the strength characteristics of the pulp, particularly the tearing resistance, by reducing the peripheral speed of the grinding stone. According to an article by Jan-Anders Fagerhed, "Development of wood grinding", Paperi ja Puu - Paper and Timber 72 (1990):7, the tearing resistance increases about 40 % at a grinding overpressure of 0 to 1 bar when the peripheral speed of the grinding stone is reduced from 30 m/s to 10 m/s. Correspondingly, the tearing resistance increases about 20 % at an overpressure of 2 bar, and about 8 % at an overpressure of 3 to 4 bar. The same article also discloses that the tensile strength (at a given freeness value) can be affected to a certain amount by the peripheral speed of the grinding stone, even if the effect is not as obvious as concerning the tearing resistance. However, the tensile strength increases about 35 % when the grinding is made at atmospheric pressure and the peripheral speed is reduced from 30 m/s to 10 m/s.

[0006] In the method presented according to FI 70438 there was not proposed any variation of the peripheral speed in order to obtain an improved tearing resistance in addition to the desired freeness value.

[0007] The object of the present invention is to control the pulping process so that an optimal pulp quality is obtained, in other words so that optimal values are obtained both for the CF value of the pulp and for another quantity characterising the quality of the pulp, such as the tearing resistance, which usually is stated as the tear index (RI). As a criterion one uses the minimum sum of the squares of the system deviation from the desired levels concerning these quantities.

[0008] The features of the invention are presented in claim 1.

[0009] The method can be used in common stone pulping without overpressure (so called stone groundwood or SGW pulp) as well as in so called overpressure pulping (pressure groundwood or PGW).

[0010] In principle the pulping process can be controlled by two control variables, i.a. the wood supply rate (or power) and the peripheral speed of the grinding stone. The supply rate can keep the CF value of the pulp at a desired level, and the peripheral speed of the stone can keep another variable at a desired level. Thus it is possible to control the process by a multivariable method with two input signals and two output signals.

[0011] The control can be effected with the aid of a multivariable control algorithm or with two SISO loops (single input, single output).

[0012] The CF value and the tear index of the pulp are kept on a desired level, and the sum of the deviations

$$(CF_x - CF_0)^2 + (RI_x - RI_0)^2$$

is minimised, where CF_0 = freeness set point; CF_x = measured freeness value; RI_0 = tear index set point; and RI_x = measured value of the tear index.

[0013] The multivariable control algorithm can also be made adaptive in order to compensate for changes in the grinding stone's sharpness with time.

[0014] The relation between the grinding stone's sharpness and the properties of the mass has been earlier published (see for instance Georg v. Alftan, "Valmistusolojen vaikutus mekaanisen massan ominaisuuksiin", in the textbook "Pukemia", Waldemar Jensen, Helsinki 1967).

[0015] Measurement data which has been published by Jan-Anders Fagerhed (Development of wood grinding, Part 3 Effects of casing pressure and pulpstone speed, Paperi-Puu - Paper and Timber 72 (1990):7, 680 - 686) and which

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is supplemented by previously unpublished material are presented below.

[0016] A list of the symbols used below:

m =	mass flow	() kg/h
P =	grinding overpressure	() bar
F _n =	supply pressure	() N
V _n =	supply rate	() mm/s
V _p =	peripheral speed	() m/s
SER =	specific energy requirement	() MWh/t
Tear =	tear index	() mNm ² /g
CFS =	Canadian Standard Freeness	() ml

Results:

[0017]

Table 1:

P ₀ T = 80 °C +/- 1 °C							
m kg/h	P bar	F _n N	V _n mm/s	V _p m/s	SER MWh/t	Tear mNm ² /g	CFS ml
0.97	0	180	0.56	30.0	1.90	2.90	68
1.97	0	200	0.71	30.0	1.52	3.00	120
1.60	0	265	0.85	30.0	1.37	2.80	146
1.85	0	240	1.05	30.0	1.26	2.90	157
0.84	0	185	0.56	20.0	1.58	3.85	75
1.17	0	320	0.64	20.0	1.38	3.80	110
1.47	0	290	0.80	20.0	1.23	3.40	110
1.57	0	355	0.92	20.0	1.07	3.15	180
0.66	0	280	0.36	10.1	1.44	3.75	90
0.92	0	380	0.50	10.0	1.29	4.20	100
1.12	0	500	0.58	9.9	1.14	4.35	150
1.23	0	465	0.69	10.0	1.01	4.20	170

Table 2:

P ₁ T = 95 °C +/- 1 °C							
m kg/h	P bar	F _n N	V _n mm/s	V _p m/s	SER MWh/t	Tear mNm ² /g	CFS ml
0.99	1.0	110	0.41	30.0	1.79	3.70	90
1.07	1.0	170	0.53	30.0	1.84	3.90	65
1.28	1.0	200	0.63	30.0	1.55	3.85	105
1.50	1.0	225	0.74	30.0	1.40	3.25	120
0.75	1.0	150	0.38	20.0	1.57	4.65	90
1.00	1.0	245	0.48	20.0	1.45	4.40	85
1.28	1.0	265	0.59	20.1	1.15	5.15	140
1.34	1.0	230	0.69	20.0	1.31	4.55	60
0.64	1.0	335	0.30	10.0	1.38	5.35	85
0.79	1.0	420	0.38	10.0	1.02	4.95	95
1.04	1.0	435	0.49	10.0	1.09	5.30	110

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Table 2: (continued)

P ₁ T = 95 °C +/- 1 °C							
m kg/h	P bar	F _n N	V _n mm/s	V _p m/s	SER MWh/t	Tear mNm ² /g	CFS ml
1.18	1.0	460	0.59	10.0	0.93	5.45	120

Table 3:

P ₂ T = 110 °C +/- 1 °C							
m kg/h	P bar	F _n N	V _n mm/s	V _p m/s	SER MWh/t	Tear mNm ² /g	CFS ml
0.94	2.0	110	0.51	30.0	1.61	4.55	120
1.28	2.0	210	0.62	30.0	1.39	5.05	130
1.66	2.0	200	0.76	30.0	1.06	4.80	220
1.88	2.0	195	0.94	30.0	1.18	4.50	175
0.81	2.0	80	0.41	20.0	1.34	5.40	100
0.88	2.0	210	0.51	20.0	1.20	5.10	145
1.35	2.0	310	0.61	20.0	1.45	5.25	135
1.44	2.0	220	0.69	20.0	1.67	4.70	95
0.57	2.0	285	0.28	10.0	1.44	5.85	75
0.73	2.0	355	0.38	10.0	1.24	5.55	160
1.01	2.0	425	0.49	9.9	1.09	5.10	195
1.21	1.9	475	0.59	10.0	0.95	6.05	255

Table 4:

P ₃ T = 120 °C +/- 1 °C							
m kg/h	P bar	F _n N	V _n mm/s	V _p m/s	SER MWh/t	Tear mNm ² /g	CFS ml
0.76	3.0	75	0.40	30.0	1.67	5.35	75
1.01	3.0	135	0.50	30.0	1.39	5.25	105
1.26	3.0	150	0.60	30.0	1.20	5.45	100
1.48	3.0	155	0.72	30.0	1.24	5.75	100
0.74	3.0	130	0.35	20.0	1.30	5.90	100
0.94	3.0	250	0.45	20.0	1.42	5.55	60
1.10	3.0	255	0.56	20.0	1.45	5.85	70
1.29	3.0	225	0.67	20.0	1.12	5.75	140
0.58	3.0	310	0.28	10.0	1.52	6.00	100
0.70	3.0	350	0.36	10.0	1.40	5.65	115
0.89	3.0	420	0.46	10.0	1.19	5.80	175
1.05	3.0	480	0.54	10.0	1.19	6.45	150

Table 5:

P ₄ T = 130 °C +/- 1 °C							
m kg/h	P bar	F _n N	V _n mm/s	V _p m/s	SER MWh/t	Tear mNm ² /g	CSF ml
0.77	4.0	95	0.40	30.0	1.71	5.35	70
0.95	4.0	120	0.50	30.1	1.60	4.95	65

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Table 5: (continued)

P ₄ T = 130 °C +/- 1 °C							
m kg/h	P bar	F _n N	V _n mm/s	V _p m/s	SER MWh/t	Tear mNm ² /g	CSF ml
1.05	4.0	145	0.58	30.0	1.25	5.30	120
1.26	4.0	165	0.67	30.1	1.09	5.00	155
0.64	4.0	120	0.33	20.0	1.06	5.75	130
0.81	4.0	205	0.42	20.0	1.45	5.60	85
1.00	4.0	185	0.52	20.0	1.35	5.50	100
1.23	4.0	190	0.62	20.0	1.11	5.45	135
0.48	4.0	265	0.25	10.0	1.61	5.55	80
0.60	4.0	365	0.33	10.0	1.34	5.40	155
0.79	4.0	375	0.42	10.0	0.22	6.10	180
1.01	4.0	385	0.53	10.0	0.97	5.90	230

Table 6:

P ₅ T = 140 °C							
m kg/h	P bar	F _n N	V _n mm/s	V _p m/s	SER MWh/t	Tear mNm ² /g	CSF ml
0.80	5.0	175	0.39	30.1	1.64	5.30	80
0.98	5.0	165	0.50	30.0	1.28	5.70	95
1.21	5.0	125	0.60	30.0	1.02	5.40	215
1.29	5.0	160	0.69	30.1	1.19	5.75	125
0.70	5.0	180	0.33	20.0	1.56	5.65	65
0.85	5.0	140	0.42	20.0	1.13	5.35	120
0.93	5.0	155	0.51	20.0	1.19	5.70	120
1.19	5.0	225	0.60	20.0	1.03	5.35	145
0.45	5.0	215	0.25	10.0	1.51	5.65	65
0.62	5.0	320	0.32	10.0	1.41	6.45	150
0.41	5.0	210	0.21	10.0	1.49	4.85	75
0.77	5.0	270	0.42	10.0	1.11	6.10	210

[0018] The relation between quantities characterising the pulp properties (freeness, tear index) and the operating conditions of the process can be determined by regression analysis based on the measurement data presented above.

[0019] The results show that the mass flow can be kept rather constant despite the lower peripheral speeds because the supply pressure is increased.

[0020] The method according to the invention also reduces the specific energy consumption (SER).

Control methodics:

[0021] An adaptive (self-adjusting) control algorithm is presented below. The controller is a generalisation of the multivariable control algorithm of Åström and Wittenmark (1973).

[0022] The process can be described by the equation below:

$$\begin{aligned}
 y(t) + A_1 y(t-1) + \dots + A_n y(t-n) = \\
 = B_0 u(t-k-1) + \dots + B_{n-1} u(t-k-n) + e(t) +
 \end{aligned}$$

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$$+ C_1 e(t-1) + \dots + C_n e(t-n) \quad (1)$$

5 where u is the input vector and y is the output vector, and $\{e(t)\}$ is a sequence of independent evenly distributed random vectors with a mean value of zero and the covariance

$$E[e(t)e^T(t)] = R$$

10 **[0023]** The dimension of all vectors u , y and e is p , and the dimension of all matrices A_i , B_i and C_i is $p \times p$. The matrix B_0 is non-singular.

[0024] Now we introduce the shift operator q^{-1} defined as

$$15 \quad q^{-1}(t) = y(t-1)$$

and the polynomial matrices

$$20 \quad A(z) = I + A_1 z + \dots + A_n z^n$$

$$B(z) = B_0 + B_1 z + \dots + B_{n-1} z^{n-1}$$

$$25 \quad C(z) = I + C_1 z + \dots + C_n z^n$$

[0025] It is assumed that all zeros of $B(z)$ are outside the unit circle. B_0 is non-singular. The system (1) can be written as

$$30 \quad A(q^{-1})y(t) = B(q^{-1})u(t-k-1) + C(q^{-1})e(t) \quad (2)$$

[0026] In each sampling interval the adaptive algorithm performs an identification based on the least squares method according to the model presented below.

[0027] The obtained parameters are used for calculation of the control strategy.

Estimation

40 **[0028]** The algorithm estimates the parameters for the model

$$y(t) + A(q^{-1})y(t) = B(q^{-1})y(t-k-1) + \varepsilon(t) \quad (3)$$

45 so that the error $\varepsilon(t)$ is minimised according to the least squares.

[0029] In the model (3) k is selected as the dead time for the process (2), and $A(z)$ and $B(z)$ are $p \times p$ polynomial matrices according to

$$50 \quad A(z) = A_0 + A_1 z + \dots + A_{nA} z^{nA}$$

$$B(z) = B_0 + B_1 z + \dots + B_{nB} z^{nB}$$

55 **[0030]** First we assume that

$$B_0 = I$$

and

5

$$B_0 = I$$

where B_0 is a matrix in the constant term of $B(z)$ for the process (2).

10 **[0031]** Now we introduce the column vectors

$$\theta_i = [\alpha_{i1}^0 \dots \alpha_{ip}^0 \dots \alpha_{i1}^{nA} \dots \alpha_{ip}^{nA} \dots \alpha_{i1}^1 \dots \alpha_{ip}^1 \dots \alpha_{i1}^{nB} \dots \alpha_{ip}^{nB}]^T, \quad i = 1, \dots, p \quad (4)$$

15

where α_{ij}^k is the (i,j) th element in the matrix A_k ; β_{ij}^k is the (i,j) th element in the matrix B_k , and so on. Then the column vector θ_i can be considered to contain the coefficients of the i th row in the model (3).

20 **[0032]** Further we introduce the row vector

20

$$\phi(t-k-1) = [-y^T(t-k-1) \dots -y^T(t-k-1-n_A) \dots u^T(t-k-2) \dots u^T(t-k-1-n_B)] \quad (5)$$

25

[0033] The i th row in model (3) can be written as

$$\varepsilon(t) = y_i(t) - u_i(t-k-1) - \phi(t-k-1)\theta_i$$

30

[0034] According to the least squares criterion the vector θ_i at each moment N is calculated so that

35

$$V_N(\theta_i) = 1/N \sum_{t=1}^N \varepsilon_i^2(t), \quad i = 1, \dots, p \quad (6)$$

is minimised. This results in a least squares estimation of each row in (2) based on data which is available at the moment N . When N is large, the initial values are of insignificant importance in (6). The criterion (6) can be written as

40

$$V_N(\theta_i) = 1/N \sum_{t=1}^N [y_i(t) - u_i(t-k-1) - \phi(t-k-1)\theta_i]^2$$

$$i = 1, \dots, p \quad (7)$$

45

50 **[0035]** The value $\hat{\theta}_i$ which minimises (7) is given by the normal equations, see Åström and Eykhoff (1971).

50

55

$$\begin{aligned}
 & \left[\sum_{t=1}^N \phi^T(t-k-1)\phi(t-k-1) \right] \hat{\theta}_i(N) = \\
 & = \sum_{t=1}^N \phi^T(t-k-1)[y_i(t)-u_i(t-k-1)] \\
 & \quad i = 1, \dots, p \quad (8)
 \end{aligned}$$

Control

[0036] At each moment t the control strategy is calculated from

$$B(q^{-1})u(t) = A(q^{-1})y(t) \quad (9)$$

where the *polynomial matrices* $A(z)$ and $B(z)$ are obtained from the current value of the estimated parameters. The control strategy can be written as

$$u_i(t) = -\hat{\phi}(t)\hat{\theta}_i(t) \quad i = 1, \dots, p \quad (10)$$

The parameters for the controller are the same as the estimated parameters. When we use

$$\hat{\theta} = [\hat{\theta}_1, \hat{\theta}_2, \dots, \hat{\theta}_p] \quad (11)$$

the strategy (10) can be written as

$$u^T(t) = -\hat{\phi}(t)\hat{\theta}(t) \quad (12)$$

[0037] The estimated parameter vector $\hat{\theta}_i$ in (8) can be recursively calculated from

$$\hat{\theta}_i(t) = \hat{\theta}_i(t-1) + K(t-1)[y_i(t) - u_i(t-k-1) - \hat{\phi}(t-k-1)\hat{\theta}_i(t-1)]$$

$$K(t-1) = P(t-1)\phi^T(t-k-1)[1 + \phi(t-k-1)P(t-1)\phi^T(t-k-1)]^{-1} \quad (13)$$

$$P(t) = P(t-1) - K(t-1)[1 + \phi(t-k-1)P(t-1)\phi^T(t-k-1)]K^T(t-1)$$

[0038] $P(t)$ is a normalised covariance matrix of the estimated parameters $\hat{\theta}_i$.

[0039] The initial values of $P(t)$ are assumed to be the same for all parameter vectors $\hat{\theta}_i$. The corresponding amplification vectors $K(t-1)$ will also be the same for all estimators.

[0040] Sometimes it may be useful to introduce an exponential weighting for the parameter estimation. This can be done by modifying the criterion (6) to

$$\sum_{t=1}^N \lambda^{N+1-t} \epsilon_i^2(t) \quad i = 1, \dots, p; \quad \lambda \leq 1 \quad (14)$$

[0041] The last equation in (13) changes to

$$P(t) = 1/\lambda \{ P(t-1) - K(t-1) [1 + \phi(t-k-1) P(t-1) \phi^T(t-k-1)] \times K^T(t-1) \} \quad (15)$$

[0042] Another possibility is to use Kalman filters. The covariance matrix $P(t)$ is supplemented by adding to it a matrix R_1 instead of the division by λ .

[0043] Then the equation (15) will be

$$P(t) = P(t-1) - K(t-1) [1 + \phi(t-k-1) P(t-1) \phi^T(t-k-1)] \times K^T(t-1) + R_1$$

[0044] It should be noted that the algorithm can be construed as a union of a plurality (here 2) of simple self-adjusting controllers. For instance the controller 2 controls the output signal $y_2(t)$ by using the control variable $u_2(t)$. $y_1(t-i)$ and $u_1(t-1-i)$ ($i \geq 0$) can be used as feedforward signals. This means that the two simple self-adjusting controllers can operate in a cascade mode.

[0045] The possibilities for this feature strongly depend on the process properties regarding the model (2) and character of the minimum variance strategy. The multivariable self-adjusting control algorithm can in some circumstances result in the minimum variance, in other words when $C(z) = I$ (the process interference is white noise).

[0046] Another possibility is an exclusively multivariable minimum variance control algorithm, which is not adaptive.

[0047] At a pulping overpressure of 0 to 2 bar the control of the tear index at lower peripheral speeds results in great advantages (40 % to 20 %). As the multivariable control algorithm also is adaptive, changed sharpness is taken into account by increasing the peripheral speed. During this the freeness can be freely selected.

[0048] At higher pulping overpressures the advantage is an improvement of about 10 % concerning the tear index, and the changes in sharpness can be controlled in the periods between sharpening actions. During these periods the freeness can be freely selected.

[0049] If the sharpening is not made with pressurised water or similar at regular intervals, then the sharpening is made at P_{max} at the maximum power consumption.

Claims

1. A method for the control of a groundwood pulping process, whereby pulpwood logs are pressed against the periphery of a rotating grinding stone, the grinding stone is sprayed with water, and the generated fiber suspension, the pulp, is stored, **characterised in that** the drainability or the freeness CF of the pulp and another quantity Q characterising the pulp quality are measured, the measured values CF_x and Q_x are compared with the set points CF_0 and Q_0 of the corresponding quantities, and the wood supply rate V_n or the wood supply pressure F_n , and the grinding stone's peripheral speed V_p are adjusted so that the sum $(CF_x - CF_0)^2 + (Q_x - Q_0)^2$ obtains its minimum value.
2. A method according to claim 1, **characterised in that** the quantity Q is a measure of the tearing resistance of the pulp, for instance the tear index RI.
3. A method according to claim 1 or 2, **characterised in that** the control is effected with the aid of a multivariable control algorithm.
4. A method according to claim 3, **characterised in that** the multivariable control algorithm is adaptive in order to compensate for changes in the grinding stone's sharpness with time.

Patentansprüche

1. Verfahren zur Steuerung eines Holzschliffherzeugungsvorgangs, wobei Faserholzblöcke gegen die Peripherie eines

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rotierenden Schleifsteins gedrückt werden, der Schleifstein mit Wasser besprüht wird, und die erzeugte Faserlösung, die Pulpe, gespeichert wird, **dadurch gekennzeichnet, dass** die Entwässerbarkeit oder Entwässerungsfähigkeit CF der Pulpe und eine andere Größe Q, welche die Qualität der Pulpe charakterisiert, gemessen werden, die gemessenen Werte CF_x und Q_x mit den Sollwerten CF_0 und Q_0 der entsprechenden Größen verglichen werden, und die Holzzufuhr rate V_n oder der Holzzufuhrdruck F_n und die Peripheriegeschwindigkeit V_p des Schleifsteins so geregelt werden, dass die Summe $(CF_x - F_0)^2 + (Q_x - Q_0)^2$ ihren minimalen Wert annimmt.

2. Verfahren nach Anspruch 1, **dadurch gekennzeichnet, dass** die Größe Q ein Maß für die Reißfestigkeit der Pulpe, zum Beispiel der Tear-Index RI, ist.
3. Verfahren nach Anspruch 1 oder 2, **dadurch gekennzeichnet, dass** die Steuerung mit Hilfe eines Mehrvariablenregelungsalgorithmus bewerkstelligt wird.
4. Verfahren nach Anspruch 3, **dadurch gekennzeichnet, dass** der Mehrvariablenregelungsalgorithmus adaptiv ist, um mit der Zeit auftretende Änderungen der Schärfe des Schleifsteins auszugleichen.

Revendications

1. Procédé pour le contrôle d'un processus de fabrication de pâtes mécaniques, moyennant quoi des rondins de bois à pâte sont appuyés contre la périphérie d'une meule rotative, la meule est pulvérisée avec de l'eau et la suspension de fibres produite, à savoir la pâte, est stockée, **caractérisé en ce que** l'égouttabilité ou l'indice d'égouttabilité CF de la pâte et une autre quantité Q caractérisant la qualité de la pâte sont mesurés, **en ce que** les valeurs mesurées CF_x et Q_x sont comparées aux points de contrôle CF_0 et Q_0 des quantités correspondantes, et **en ce que** le taux d'alimentation en bois V_n ou la pression d'alimentation en bois F_n et la vitesse périphérique de la meule V_p sont ajustés de telle sorte que la somme $(CF_x - CF_0)^2 + (Q_x - Q_0)^2$ obtient sa valeur minimale.
2. Procédé selon la revendication 1, **caractérisé en ce que** la quantité Q est une mesure de la résistance au déchirement de la pâte, par exemple l'indice de cisaillement RI.
3. Procédé selon la revendication 1 ou 2, **caractérisé en ce que** le contrôle est effectué à l'aide d'un algorithme de contrôle multivariable.
4. Procédé selon la revendication 3, **caractérisé en ce que** l'algorithme de contrôle multivariable peut être adapté afin de compenser les variations du tranchant de la meule au cours du temps.