Set-Up Generation System for a Tandem Cold Mill

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Abstract—In this paper an alternative set-up generation system is developed for a tandem cold mill to be used during emergency operation in case of shut-down of the main operating mode. The system is based on a cost function that evaluates the mill quality and productivity for each set-up. This cost function is minimized using the Nelder and Mead simplex method. Despite to be simpler than the main set-up generation system, it is faster, more accurate and safer than the usual emergency mode, which is based on a set of tables.

NOMENCLATURE

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_R$</td>
<td>Young’s modulus for the work roll</td>
</tr>
<tr>
<td>$E_S$</td>
<td>Young’s modulus for the strip</td>
</tr>
<tr>
<td>$F$</td>
<td>Total roll force ($F = PL$)</td>
</tr>
<tr>
<td>$f$</td>
<td>Forward slip</td>
</tr>
<tr>
<td>$F_{MAX}^{i}$</td>
<td>Maximum roll force at stand $i$</td>
</tr>
<tr>
<td>$F_{MIN}^{i}$</td>
<td>Minimum roll force at stand $i$</td>
</tr>
<tr>
<td>$G$</td>
<td>Roll torque per unit width</td>
</tr>
<tr>
<td>$h^{(j)}$</td>
<td>Strip thickness at interstand zone $j$</td>
</tr>
<tr>
<td>$h_1$</td>
<td>Stand input thickness</td>
</tr>
<tr>
<td>$h_2$</td>
<td>Stand output thickness</td>
</tr>
<tr>
<td>$J$</td>
<td>Cost function</td>
</tr>
<tr>
<td>$J_{F}^{i}$</td>
<td>Roll force part of the cost function at stand $i$</td>
</tr>
<tr>
<td>$J_{L}^{(j)}$</td>
<td>Tension part of the cost function at interstand zone $j$</td>
</tr>
<tr>
<td>$J_{W}^{(i)}$</td>
<td>Motor power part of the cost function at stand $i$</td>
</tr>
<tr>
<td>$k_1$</td>
<td>Stand input yield stress</td>
</tr>
<tr>
<td>$k_2$</td>
<td>Stand output yield stress</td>
</tr>
<tr>
<td>$L$</td>
<td>Strip width</td>
</tr>
<tr>
<td>$P$</td>
<td>Roll force per unit width</td>
</tr>
<tr>
<td>$R$</td>
<td>Undefomed work roll radius</td>
</tr>
<tr>
<td>$R'$</td>
<td>Deformed work roll radius</td>
</tr>
<tr>
<td>$T$</td>
<td>Total interstand tension ($T = \sigma L$)</td>
</tr>
<tr>
<td>$T_{MAX}^{(j)}$</td>
<td>Maximum tension stress at interstand zone $j$</td>
</tr>
<tr>
<td>$T_{MIN}^{(j)}$</td>
<td>Minimum tension stress at interstand zone $j$</td>
</tr>
<tr>
<td>$V$</td>
<td>Work roll linear speed</td>
</tr>
<tr>
<td>$V_1$</td>
<td>Stand input strip speed</td>
</tr>
<tr>
<td>$V_2$</td>
<td>Stand output strip speed</td>
</tr>
<tr>
<td>$W$</td>
<td>Motor power</td>
</tr>
<tr>
<td>$W_{MAX}^{i}$</td>
<td>Maximum motor power at stand $i$</td>
</tr>
<tr>
<td>$W_{MIN}^{i}$</td>
<td>Minimum motor power at stand $i$</td>
</tr>
<tr>
<td>$x$</td>
<td>Vertices of the simplex</td>
</tr>
<tr>
<td>$\phi_N$</td>
<td>Angle at neutral plane</td>
</tr>
<tr>
<td>$\sigma^{(j)}$</td>
<td>Tension stress at interstand zone $j$</td>
</tr>
<tr>
<td>$\sigma_1$</td>
<td>Stand input tension stress</td>
</tr>
<tr>
<td>$\sigma_2$</td>
<td>Stand output tension stress</td>
</tr>
<tr>
<td>$u_R$</td>
<td>Poisson’s ratio for the work roll</td>
</tr>
<tr>
<td>$u_S$</td>
<td>Poisson’s ratio for the strip</td>
</tr>
<tr>
<td>$\varepsilon$</td>
<td>Logarithmic reduction</td>
</tr>
</tbody>
</table>

Subscripts and Superscripts

1 Stand input parameter
2 Stand output parameter
- Parameter mean value
i Stand number
j Interstand zone number
$MAX$ Parameter maximum value
$MIN$ Parameter minimum value

I. INTRODUCTION

Set-up generation is an important aspect in the operation of tandem cold mills. It defines stand reductions, speeds and power for the drives, roll forces and interstand tensions for the tandem cold mill control system. Set-up optimization should lead to improved thickness, surface finish and shape performance of the products. The importance of such optimization first appeared in [1] and it has been object of several works [2]–[5].

In case of malfunction of the main processing unit responsible to execute the set-up generation system of Cosipa tandem cold mill, a Brazilian steel industry, the normal procedure for the operation is interrupted and an emergency operation mode is then activated. As the process unit has low failure rate, the high cost of a redundant system implementation is not justified. This is the main reason for the development of an alternative simpler system for set-up generation, as presented in this work.

The proposed system is based on a cost function that evaluates the mill quality and productivity for each set-up. The cost function is minimized using the Nelder and Mead simplex method [6], and the process variables, involved in the cost function, are evaluated by the cold rolling model proposed by Bryant and Osborn [7], [8].

The organization of this paper is as follows. In section II the mechanical and electrical characteristics of the tandem cold mill are presented and the automation architecture is described. The cold mill model used to estimate process variables is presented in section III. In section IV, the cost function and
the optimization algorithm for the minimization of the cost function are presented. In section V, the set-up calculated by the proposed system is compared with the set-up calculated by the system used under normal operation mode. Finally, in section VI, the main conclusions are presented.

II. PLANT DESCRIPTION

The described system was developed and implemented at Cosipa tandem cold mill plant. The cold rolling mill considered is a coil to coil, four high, four stand mill, in which each stand is driven by two twin independent dc motors. Two hydraulics actuators, installed at the top of the stand, complete the set of reduction of each stand. Fig. 1 shows a schematic diagram of the tandem cold mill and Table I presents its main electrical and mechanical characteristics.

Prior to rolling, set-up is calculated based on expected steady-state mill behavior. The threading process, where the strip is successively introduced into the mill stands, occurs at low speed. After the last stand is threaded, the mill is accelerated to the desired operating speed. At the end of the coil, the mill is decelerated to a low speed for the dethreading of the strip from each stand and simultaneously the tandem cold mill must be set-up for the next coil.

The whole mill is commanded by a control system, whose architecture is shown in Fig. 2. The automation architecture of Cosipa four stand tandem cold mill is composed mainly of 4 levels, as described in [9]:

- Level 3 (Production planning level): This level is responsible to decide which product will be produced and according to which specification.
- Level 2 (Process optimization level): After receiving the entry and exit product specification, this level is responsible to find the best set-up of the mill in order to ensure the highest quality and the maximum productivity. It contains mainly the static model and functions to track the coils at this level.
- Level 1 (Process dynamic control): This level is responsible to generate the adequate references for the actuators according to the orders received from level 2. To do this, it includes the dynamic model and the mill master logic.
- Level 0 (Actuators and sensors): This level is responsible to execute the orders received from level 1. It includes equipment such as drives of the main motors and hydraulics gap control.

Set-up generation is performed in level 2 of the automation architecture. Given the coil characteristics to be processed, there are infinite combinations of reduction and tension between stands which can provide the desired final characteristics. However, each reduction and tension between stands implies distinct roll forces and motor powers. Furthermore, operational restriction of equipments must be considered.

The main set-up system is composed by a cost function which evaluates how far roll forces, motor powers and interstand tensions are from the ideal one specified, chosen by process engineers. The cost function is minimized by the Nelder and Mead simplex method [6] and process variables involved are estimated by Bland and Ford cold mill model [10], [11].

In case of malfunction of the main processing unit responsi-
ble for the execution of level 2 automation system (CPU DEC Alpha Server 1000 – A), the mill set-up generation is frozen.

The same occurs in case of a communication interruption between levels 2 and 3. The present emergency operation mode consists in finding the more suitable set-up value from tables previously constructed for the most common materials.

This alternative represents a significant decreasing of performance in relation to the normal operation mode. As a coil to coil process, it occurs frequently that specific coil characteristics are not found in such tables. In this case, the processing time is increased, decreasing the mill productivity and quality.

With a low hardware failure rate, redundancy implementation is not justified, and the use of more detailed set-up tables, besides not to include all types of materials, may increase even more the time for checking. Hence the decision was to develop another set-up generation system, described hereafter in this paper.

III. THE PROCESS MODEL

Cold mill process models have been developed for more than half century. The most classic cold mill process model, proposed by Bland and Ford [10], [11], is composed by algebraic and integrals equations for forces and torques calculation. Bryant and Osborn [7], [8], through model simplifications, developed a cold mill model composed only by algebraic equations. This simple model demands low computational effort and shows satisfactory results. The set-up generation system here considered uses Bryant and Osborn cold mill model for roll forces and roll torques calculation. Fig. 3 shows main roll-gap variables used in the model.

A. Force Model

Bryant and Osborn [7] proposed the following equation to calculate roll force per width of strip

\[ P = \frac{P_0}{1 - 0.4\alpha B_0 - bP_0} \]  

(1)

where

\[ P_0 = (\bar{k} - \bar{\sigma})\sqrt{R\delta}(1 + 0.4\alpha_0) + P_{E0} \]  

(2)

\[ \delta = h_1 - h_2 \]  

(3)

\[ \alpha_0 = \frac{h_2}{h_1}\exp\left(\frac{\mu\sqrt{R\delta}}{h}\right) - 1 \]  

(4)

\[ \bar{h} = 0.28h_1 + 0.72h_2 \]  

(5)

\[ P_{E0} = \frac{2}{3}(k_2 - \sigma_2)^{1.5}\sqrt{R\delta(1 - \frac{v^2}{E}}) \]  

(6)

\[ a = 1.4\sqrt{\frac{h_2}{h_1}\left(\frac{\mu}{h}\right)^2 R\delta} \]  

(7)

\[ b = \frac{c}{2\delta} - \frac{P_0}{2}\left(\frac{c}{2\delta}\right)^2 \]  

(8)

\[ B_0 = (\bar{k} - \bar{\sigma})\sqrt{R\delta} \]  

(9)

\[ c = \frac{4(1 - \frac{v^2}{E})}{\pi R} \]  

(10)

\[ \bar{\sigma} = \frac{2}{3}\sigma_1 + \frac{1}{3}\sigma_2 \]  

(11)

\[ \bar{k} = \frac{1}{3}k_1 + \frac{2}{3}k_2 \]  

(12)

The yield stress at entry and exit from each stand can be evaluated by

\[ k_p = k_0(\lambda_1 + \lambda_2\varepsilon_p)[1 - \lambda_3\exp(-\lambda_4\varepsilon_p)] \]  

(13)

\[ \varepsilon_p = \ln \frac{h_0}{h_p} \]  

(14)

where \( k_0 \) and \( \lambda_1, \lambda_2, \lambda_3, \lambda_4 \) are constants and \( p = 1 \) to variable at entry to stand and \( p = 2 \) to variable at exit from stand.

B. Torque and Power Model

The roll torque per width of strip is given by the following equation [8]

\[ G = RPC + \frac{R}{2}(h_1\sigma_1 - h_2\sigma_2) \]  

(15)

where

\[ C = \sqrt{\frac{\delta}{R'}}\left(\frac{2/3)(k_1 - \sigma_1) + (1/3)(k_2 - \sigma_2)}{(k_1 - \sigma_1) + (k_2 - \sigma_2)}\right) \]  

(16)

\[ R' = R\left(1 + \frac{cP}{\delta}\right) \]  

(17)

\[ W = \frac{GLV}{\eta M T G R} \]  

(18)

\[ V = \frac{V_1h_1}{(1 + f)h_2} \]  

(19)


\[ V_1 = \frac{V_2 h_2}{h_1} \]  

\[ f = \frac{R' \phi_N^2}{h_2} \]  

\[ \phi_N = \frac{1}{2h} \sqrt{\frac{\delta}{R'}} - \frac{1}{4hR'} \left( \frac{\sigma_2}{k_2} - \frac{\sigma_1}{k_1} \right) \]

IV. SET-UP OPTIMIZATION

A. Cost Function

The definition of an optimum set-up for a given set of mill conditions is largely subjective [12]. In a cost function involving roll forces, motor powers and interstand tensions, the relative weighting of the various items remains a matter of judgement. The cost function in the set-up generation system is given by

\[ J(x) = \sum_{i=1}^{4} \left[ J_W^{(i)}(x) + J_F^{(i)}(x) \right] + \sum_{j=2}^{4} J_T^{(j)}(x) \]

where

\[ x = \left( h_1^{(2)}, h_3^{(3)}, h_4^{(4)}, \sigma_2^{(2)}, \sigma_3^{(3)}, \sigma_4^{(4)} \right) \]

Thicknesses and tensions between payoff and the first stand, \( h_1^{(1)} \) and \( \sigma_1^{(1)} \), and thicknesses and tensions between the last stand and tension reel, \( h_5^{(5)} \) and \( \sigma_5^{(5)} \), are fixed during the cost function minimization. The entry and exit stand thicknesses and tensions, necessary to calculate roll forces and motor powers are given by

\[ h_1^{(i)} = h_2^{(i+1)} = h^{(j)} \]  

\[ \sigma_1^{(i)} = \sigma_2^{(i+1)} = \sigma^{(j)} \]

The parts of the cost function correspondent to roll forces, motor powers and interstand tensions are given by

\[ J_W^{(i)} = K_W^{(i)} \left( \frac{W^{(i)} - \frac{W_{M}\hat{W}_{M}+W_{M}}{2}}{W_{M}\hat{W}_{M}+W_{M} \hat{W}_{M}} \right) \]

\[ J_F^{(i)} = K_F^{(i)} \left( \frac{F^{(i)} - \frac{F_{M}\hat{F}_{M}+F_{M}}{2}}{F_{M}\hat{F}_{M}+F_{M} \hat{F}_{M}} \right) \]

\[ J_T^{(j)} = K_T^{(j)} \left( \frac{T^{(j)} - \frac{T_{M}\hat{T}_{M}+T_{M}}{2}}{T_{M}\hat{T}_{M}+T_{M} \hat{T}_{M}} \right) \]

Motor powers, roll forces and interstand tensions must stay between maximum and minimum values defined by process engineers. Total power close to the total available value, provide higher productivity. Roll force greatly affect strip surface quality. Finally, tension must not exceed maximum and minimum limits in order to avoid looping or strip break.

The coefficients and exponents of the cost function (K and N) are chosen so as to balance the weight of each stand or interstand zone on the total cost and also to adjust their rate of change. Coefficients and exponents chosen are shown in Table II As seen in Fig. 4, the motor power cost function term (27), increases quickly if motor power exceed maximum or minimum chosen limits. The same occurs for (28) and (29).

B. Optimization Algorithm

There are several methods for functions minimization applied to cold mills optimum set-up calculation. In [3] nonlinear programming is used and in [5] a genetic algorithm is considered. Like in [2], this work uses the simplex method proposed by the Nelder and Mead [6].

An extensive explanation about the Nelder-Mead method can be found in [13]. This optimization method consists of the following steps which can be observed in Fig. 5 for a two dimensions simplex.

1) Order: Order and re-label the \( n + 1 \) vertices as \( x_1, x_2, \ldots, x_{n+1} \) so that \( J(x_1) \leq J(x_2) \leq \cdots \leq J(x_{n+1}) \). \( x_1 \) is referred as the best point or best vertex and \( x_{n+1} \) is referred as the worst.

2) Reflect: Compute the reflection point \( x_r \) by

\[ x_r = \bar{x} + (\bar{x} - x_{n+1}) \]
where \( \bar{x} \) is the centroid of the \( n \) best points, that is,
\[
\bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i
\]
(31)

Evaluate \( J(x_r) \). If \( J(x_1) \leq J(x_r) < J(x_n) \), replace \( x_{n+1} \) with the reflected point \( x_r \) and go to step 6.

3) Expand: If \( J(x_r) < J(x_1) \), compute the expansion point \( x_e \) by
\[
x_e = \bar{x} + 2(x_r - \bar{x})
\]
(32)
Evaluate \( J(x_e) \). If \( J(x_e) < J(x_1) \), replace \( x_{n+1} \) with \( x_e \) and go to step 6; otherwise, replace \( x_{n+1} \) with \( x_r \) and go to step 6.

4) Contract: If \( J(x_r) \geq J(x_n) \), perform a contraction between \( \bar{x} \) and the better of \( x_{n+1} \) and \( x_r \).
   a) Outside: If \( J(x_n) \leq J(x_r) < J(x_{n+1}) \), that is, \( x_r \) is strictly better than \( x_{n+1} \), perform an outside contraction. Calculate
\[
x_{oc} = \bar{x} + \frac{1}{2}(x_r - \bar{x})
\]
(33)
Evaluate \( J(x_{oc}) \). If \( J(x_{oc}) \leq J(x_r) \), replace \( x_{n+1} \) with \( x_{oc} \) and go to step 6; otherwise, go to step 5.
   b) Inside: If \( J(x_r) \geq J(x_{n+1}) \), perform an inside contraction. Calculate
\[
x_{ic} = \bar{x} + \frac{1}{2}(x_r - \bar{x})
\]
(34)
Evaluate \( J(x_{ic}) \). If \( J(x_{ic}) \leq J(x_{n+1}) \), replace \( x_{n+1} \) with \( x_{ic} \) and go to step 6; otherwise, go to step 5.

5) Shrink: Evaluate \( J \) at the \( n \) new vertices
\[
x'_q = x_1 + \frac{1}{2}(x_q - x_1), \quad q = 2, \ldots, n + 1
\]
(35)
Replace the vertices \( x_2, \ldots, x_{n+1} \) with the new vertices \( x'_2, \ldots, x'_{n+1} \).

6) Stopping condition: Order and re-label the vertices of the new simplex as \( x_1, x_2, \ldots, x_{n+1} \) such that \( J(x_1) \leq J(x_2) \leq \cdots \leq J(x_{n+1}) \). If \( J(x_{n+1}) - J(x_1) < \Delta \), then stop, where \( \Delta > 0 \) is a small predetermined tolerance. Otherwise go to step 2.

Point \( x \) is given by (24). To start with, the three interstand thicknesses are found by interpolation of maximum and minimum reduction limits, so that the total desired reduction is fulfilled. Hence the method is applied until the specified tolerance \( \Delta \), or a maximum number of iterations is reached. The speed of the mill is adjusted so that the maximum motors speeds and maximum motors powers for each stand are not exceeded.

V. RESULTS

The proposed set-up generation system was implemented in Matlab (The Mathworks, Inc., Natick, MA) and includes the process model and the optimization method described in the last two sections. In order to evaluate its performance, 20 coils were arbitrarily chosen. In the following, detailed set-up results for one of these 20 coils and average results for the set of 20 coils are presented.

A. Set-Up Results for One Coil

The thickness and width for the considered coil in this section are 3.01 mm and 1004 mm, respectively. The specified exit thickness is 0.91 mm. Table III presents the initial and final cost function values and the iteration number value obtained for the proposed system, based on Bryan and Osborn model - B&O, and for the main system, based on Bland and Ford model - B&F.

<table>
<thead>
<tr>
<th>TABLE III</th>
<th>PROPOSED AND MAIN SYSTEM PERFORMANCE DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computer</td>
<td>Proposed system</td>
</tr>
<tr>
<td></td>
<td>PC Pentium IV 2 GHz</td>
</tr>
<tr>
<td>Initial cost function value</td>
<td>1.83 \cdot 10^4</td>
</tr>
<tr>
<td>Final cost function value</td>
<td>20.23</td>
</tr>
<tr>
<td>Iteration number</td>
<td>198</td>
</tr>
<tr>
<td>Processing time (s)</td>
<td>0.77</td>
</tr>
</tbody>
</table>
TABLE IV
SET-UP CALCULATED FOR AN ARBITRARY CHOSEN COIL

<table>
<thead>
<tr>
<th>Zone</th>
<th>Thickness (mm)</th>
<th>Tension (ton)</th>
<th>Force (ton)</th>
<th>Speed (m/min)</th>
<th>Power (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B&amp;O</td>
<td>B&amp;F</td>
<td>B&amp;O</td>
<td>B&amp;F</td>
<td>B&amp;O</td>
</tr>
<tr>
<td>Zone 1</td>
<td>3.010</td>
<td>3.010</td>
<td>2.7</td>
<td>2.7</td>
<td>263.5</td>
</tr>
<tr>
<td>Stand 1</td>
<td>983</td>
<td>1002</td>
<td>2227.1</td>
<td>2190.2</td>
<td>573.8</td>
</tr>
<tr>
<td>Zone 2</td>
<td>2.031</td>
<td>2.047</td>
<td>22.8</td>
<td>23.9</td>
<td>390.5</td>
</tr>
<tr>
<td>Stand 2</td>
<td>979</td>
<td>940</td>
<td>2227.1</td>
<td>2190.2</td>
<td>573.8</td>
</tr>
<tr>
<td>Zone 3</td>
<td>0.989</td>
<td>0.974</td>
<td>17.8</td>
<td>17.6</td>
<td>801.8</td>
</tr>
<tr>
<td>Stand 3</td>
<td>991</td>
<td>991</td>
<td>2227.1</td>
<td>2190.2</td>
<td>573.8</td>
</tr>
</tbody>
</table>

In both cases the stop criterion was fixed in $\Delta = 0.001$. Fig. 6 illustrates the fast convergence rate of the cost function value for the proposed system, which reveals a good efficiency of the Nelder and Mead simplex optimization algorithm for this application.

The cost function values and iteration numbers in Table III are very close for both systems. The significant greater processing time of the main system is due to its more accurate calculations, as noticed in section III. In Table IV this higher precise results are taken as reference for the proposed system. The observed discrepancies were considered, by process engineers, acceptable for emergency operation.

B. Average Set-Up Results for 20 Coils

In this section the set-up parameters thickness, tension, speed, power and force were firstly calculated for 20 arbitrarily chosen coils, using the main set-up generation system. Next, the same parameters were calculated using the proposed system. Table V presents the average deviation, in percent, between the two systems, taking the main system as the base system.

The thicknesses and tensions between the payoff and the first stand (zone 1) and between the last stand and the rewind (zone 5) are fixed, and thus are not included in the simplex algorithm.

While thickness, tension and force deviations may be accepted in the ranges shown in Table V, that is, strip quality and process security specifications are maintained for these ranges, some special considerations must be made with respect to speed and power.

In fact, it was observed that the difference between the torque models for the proposed and the main system is the reason for higher speed and power values in the proposed system. In practice, this implies that some caution should be taken if the total power is exceeded, but since there is some power reserve in the case of the main system calculations, no additional action was necessary for the deviations of Table V.

The following facts resume the deviations between the set-up obtained by the two systems:

- The process model used under normal operation mode, proposed in [10], [11], is more accurate than the process model proposed in [7], [8], here adopted;
- The main system used under normal operation conditions take into account phenomenon that were not modeled by the proposed system, like strip flatness, stand stretch and thermal roll crown which in fact improve the set-up calculation;
- The friction coefficient in the main system is adapted by an inverse model, producing thus values closer to the real ones.

VI. Conclusion

In this paper a set-up generation system is developed for Cosipa tandem cold mill, a Brazilian steel industry. This set-up generation system must substitute the system used under normal operation when it becomes unavailable due to some hardware or communication failure. Although the proposed system is simpler and less accurate than the normal system, experimental results show that this is a viable alternative system.

With respect to the present emergency system, which is based on pre-calculated set-up tables, the proposed system has advantages like more precise and faster calculations.
TABLE V
AVERAGE DEVIATION IN PERCENT BETWEEN SET-UP CALCULATED BY TWO SYSTEMS

<table>
<thead>
<tr>
<th>Zone</th>
<th>Stand</th>
<th>Thickness</th>
<th>Tension</th>
<th>Force</th>
<th>Speed</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fixed</td>
<td>8.30 ± 6.99</td>
<td>Fixed</td>
<td>8.54 ± 6.99</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stand 1</td>
<td></td>
<td></td>
<td>−5.52 ± 4.78</td>
<td>3.45 ± 2.61</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>−0.27 ± 1.15</td>
<td>8.85 ± 6.76</td>
<td>8.83 ± 6.61</td>
<td>4.09 ± 2.48</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zone 3</td>
<td></td>
<td>2.31 ± 2.54</td>
<td>5.00 ± 7.04</td>
<td>6.13 ± 6.58</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stand 2</td>
<td></td>
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REFERENCES