MEASUREMENT AND PREDICTION OF THE CENTERING EFFECT OF A PROFILED ROLL ON STEEL STRIPS

by

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ABSTRACT

In a steel continuous processing line, the strip passes over an important number of rolls and strip walking can occur due to strip defects, roll profile or roll misalignment. Since decades, two solutions are used in order to keep a strip centered in the line : deflection rolls are profiled (with crowned or tapered shapes) and steering rolls are implemented, in different part of the lines.

As in other industries, the constant challenge for a line manager in the steel industry is to increase the productivity of the line and to adapt the lines to new products.

To achieve these goals on pickling lines or continuous annealing lines, it is necessary in some cases to know precisely about the centering effect of profiled rolls on the strip. This data can be used either to improve the strip centering by increasing the roll profile or to avoid other defects as wrinkles, by reducing the crown without increasing strip walking.

In order to quantify the centering efficiency of a roll, Irsid and Sollac developed a theoretical model for calculating the strip position after a profiled roll and compared it to experimental data measured on two pilot lines.

NOMENCLATURE

l	length of the span
I	inertia of the strip
E	Young Modulus of the strip
y_0	position of the strip at the entry of the span
y_r	position of the strip on the profiled roll
$y(x)$	position of the strip at the x abscise
$y(l)$	position of the strip at the exit of the profiled roll (end of the span)
$\alpha(y_0)$	centering efficiency of the roll for a given initial strip position
Lc_1	area of contact between the strip and the roll in the transverse direction (for y negative), mm
Lc_2	area of contact between the strip and the roll in the transverse direction (for y positive), mm
Lc	total area of contact, mm
$M_r(y)$	moment on the strip due to strip to profiled roll contact when the strip is at a y position, N.mm
t	thickness of the strip, mm
w	width of the strip, mm
w_{fp}	width of the flat part of the roll, mm
w_r	total width of the roll, mm
Δh	taper of the roll, mm
σ_t	uniform tensile stress applied to the strip, Mpa
σ_x	stress in the machine direction, Mpa.

INTRODUCTION

The centering effect of a profiled roll depends on many factors :

- the geometry of the line (number of rolls, distance between the rolls),
- the roll (profile, radius, friction, alignment) ,
- the strip (thickness, width, flatness, transverse direction tension profile, camber),
- the process conditions (tension, position of the line axis).

The last three parameters influence the condition of contact between the roll and the strip which clearly influence the centering efficiency of a profiled roll.

An accurate model of the centering effect of a profiled roll should describe how the roll profile combined which the rotation of the rolls lead to the centering of the strip and take into consideration the previous factors.

Irsid and Sollac developed a simplified calculation derived from work presented in previous contributions ([1],[2],[3]) and measured on steel and aluminum strips the centering effect of a profiled roll on two pilot lines. Theoretical and experimental data were compared.

MODELING THE CENTERING EFFECT OF THE PROFILED ROLL

The simplified model assumes at there is no interaction between the different spans of the line, so that each elementary part of the line can be modeled with a span with a downstream profiled roll (figure 1). The strip is bent around this roll with a given tension.

The contact area between the strip and the roll, and the tension distribution on the strip are first calculated as a function of the strip characteristics, the downstream roll profile, the tension applied and the strip displacement. The moment M_r acting on the strip is calculated from the tension distribution.

The strip position after the downstream roll is then calculated, with a mathematical formula derived from Shelton's work [1], as a function of the strip and the process parameters and the calculated moment.

The amount of centering effect is evaluated by a « centering coefficient » called α, defined as a function of the initial strip displacement y_0 and the strip position after the downstream roll y(l) :

$$\alpha(y0) = \frac{y(l) - y_0}{y_0} \times 100 \qquad \{1\}$$

In the following paragraphs the two parts of the calculation are described.

Contact and transverse tension distribution model

When a strip under tension is wrapped around a convex shaped roll, the center of the strip sustains a higher stress in the machine direction than the edges. This non uniform tension distribution when non symmetrical can generate a moment on the strip. In order to calculate the moment applied to the strip by the roll, a simple model was developed.

This model calculates the moment as a function of the strip position on the roll y_r, the length of contact and the tension distribution on the strip. If the strip is in contact with the roll between $-Lc_1$ and Lc_2 (figure 2) the moment is written as :

$$M_r(y_r) = \int_{-Lc1}^{Lc2} \sigma_x(y)(y - y_r)dy \qquad \{2\}$$

With the assumption of an elastic behavior of the strip, the tension distribution can be written as a function of the roll profile in the area of contact between the strip and the roll :

$$\sigma_x(\mathrm{y}) = \frac{1}{K_1} \times E \times \frac{\Pi}{W} \times \Delta R(y) \qquad \{3\}$$

where K_1 is a constant.

The unknown values of Lc_1 and Lc_2 can be obtained with two assumptions.

First the contact is considered to be symmetric in regard to the center of the strip :

$$Lc_1 = \frac{Lc}{2} + y_r \quad ; \; Lc_2 = \frac{Lc}{2} - y_r \qquad \{4\}$$

Then, the integration of σ_x (y) equals the tension applied to the strip :

$$\sigma_t = \frac{1}{W}\int_{-Lc1}^{Lc2} \sigma_x(y)dy\,. \qquad \{5\}$$

Finally, M_r can be expressed as a function of the strip parameters, the average tension applied, the roll profile and the position of the strip on the roll :

$$M_r(y_r) = f(\sigma_t, \Delta h, w_{fp}, w, y_r)\,. \qquad \{6\}$$

Strip position after the downstream roll

The strip position after the downstream roll is calculated with the assumptions and the equation proposed by Shelton [1] for an isolated span :

$$y(x) = C_1 \sinh(kx) + C_2 \cosh(kx) + C_3 x + C_4 \qquad \{7\}$$

$$\text{with :} \quad k = \sqrt{\frac{\sigma_t \times t \times w}{E \times I}} \qquad \{8\}$$

The boundary conditions used for the calculation of C_1 to C_4 are :

-at the upstream roll , -at the downstream roll ,

$$\begin{array}{ll} y(x=0) = y_0 & M(x=l) = M_r(y_r) \\ y'(x=0) = 0 & y'(x=l) = 0 \end{array} \qquad \{9\}$$

The strip position after the roll is thus a function of the moment calculated by the first model, the initial shifted position y_0 and the strip and the process parameters :

$$y(l) = f(\sigma t, w, l, k, t, y_0, M_r(y_r)) \qquad \{10\}$$

{7} clearly shows that y(l) depends on k.l value.

Running calculations

For our running calculations we made the following simplifications :

- we maximized the calculated moment by approximating :

$$M_r(y_r) \approx M_r(y_0) \quad \text{for} \quad 0 \le y_r \le y_0 . \qquad \{11\}$$

- we considered that the strip position on the roll and after the roll are equals.

As a consequence, the position at the exit of the roll can be expressed only with the following parameters :

$$y(l) = f(\sigma t, w, l, k, t, y_0, M_r(y_0)) . \qquad \{12\}$$

MODEL VALIDATION

Validation of the area of contact calculation [2], [3]

The total contact area Lc was compared to an evaluation of the contact area made with a FEM static model of a centered elastic strip developed for a previous study [2]. The assumptions of the calculation are :

- the roll is tapered and half of a strip is modeled (figures 3a and 3b),
- no transverse displacement is allowed on the center line of the strip and no radial displacement is possible on the flat part of the roller,
- a uniform tensile stress is applied to the strip at the end of the span.

The longitudinal and transverse stresses in the strip and the contact area between the strip and the roll are calculated for an increasing tensile stress.

The FEM calculation shows that :

- for a given tension, the magnitude of the stresses in the machine direction decrease from the center of the strip to its edge where it has even a zero value.
- at low tension the contact area is small ; for a higher tension, the contact area is more important but may still not be full.

Calculations were made with the FEM and the simplified model on a 1100 mm wide strip for different tensions applied. The total length of contact and the maximum stresses were compared and it appeared that the simplified model evaluates the maximum stresses with an error of less than 10 % (table 1).

Experimental results [5]

Profiled roll centering effect was measured in two pilot lines, in Irsid and in CRM (Centre de Recherche Métallurgique de Liège).

The measurements on the pilot lines were made within a range of k.l values of 0.2 to 1.8 ; typical k.l values for an industrial line are in the range of 0.1 to 0.9.

Measurements on Irsid pilot line

The Irsid pilot line is a high scale pilot line where industrial strips are processed at a speed up to 1000 m/mn at room temperature (figure 4). The pilot line is a closed loop with one profiled roll and ten flat rolls. The span length before the profiled roll is 7.2 meters. A strip is set at an initial shifted position before the profiled roll and the running of the strip over the crowned roll leads to strip centering. The position after the profiled roll is recorded for different tensions.

Figure 5 shows measurements for a steel strip for an initial position y_0 at the entry of the span of 100 mm. At low tensions, the centering effect is poor because the tension is not high enough for the contact between the strip and the roll taper to be established . For higher tensions, the profiled roll can correct 90% of the initial shift. The calculated values also plotted, show a good agreement with the measurements.

Measurements on CRM pilot line

In order to get experimental data in different conditions of span length and strip width, measurements were also made on the pilot line of the CRM. The pilot line is a continuous annealing line at low scale which can process 300 mm wide strips at high temperature (figure 6). The characteristics of the different spans are described in table 2.

Figure 7 show results obtained on this pilot line for a 168 mm wide aluminum strip processed at room temperature. The centering effect measured and calculated of each roll is given. A good correlation between the calculated and the measured data can be observed.

APPLICATIONS

With the models, centering coefficients could be calculated in different configurations, showing a wide range of possible values ; in continuous annealing lines for instance, centering coefficient calculated for an initial shift of 20 mm were about 10 to 20 % in the looper but lower than 5% in the furnace.

In every case, the influence of the strip to roll contact area on the centering coefficient appeared to be highly significant. Figure 8 shows that the maximal centering effect of a roll can be only reached for a high tension.

Those results could be applied to optimize the mechanical profile of the rolls. Quality improvements could be made and critical products could be processed without wrinkling defects by reducing the profile of the roll without increasing the strip walking [6].

ACKNOWLEDGMENTS

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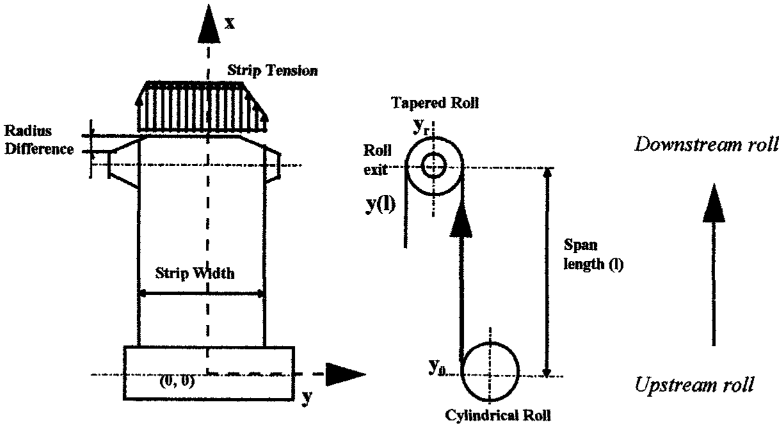


Figure 1 : a single span is considered in the model.

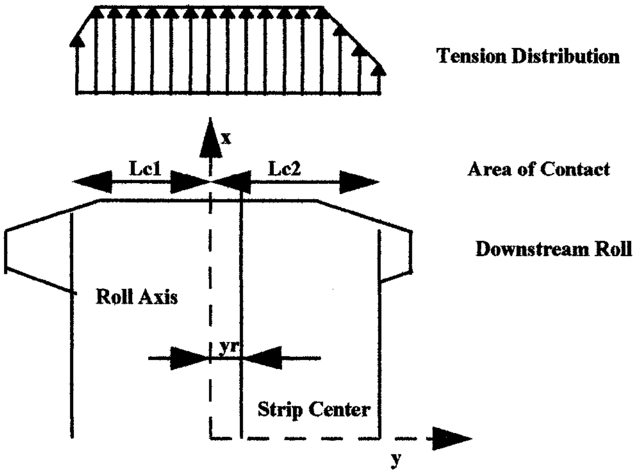


Figure 2 : centering effect of a tapered roll : effect of strip lateral displacement on tension distribution.

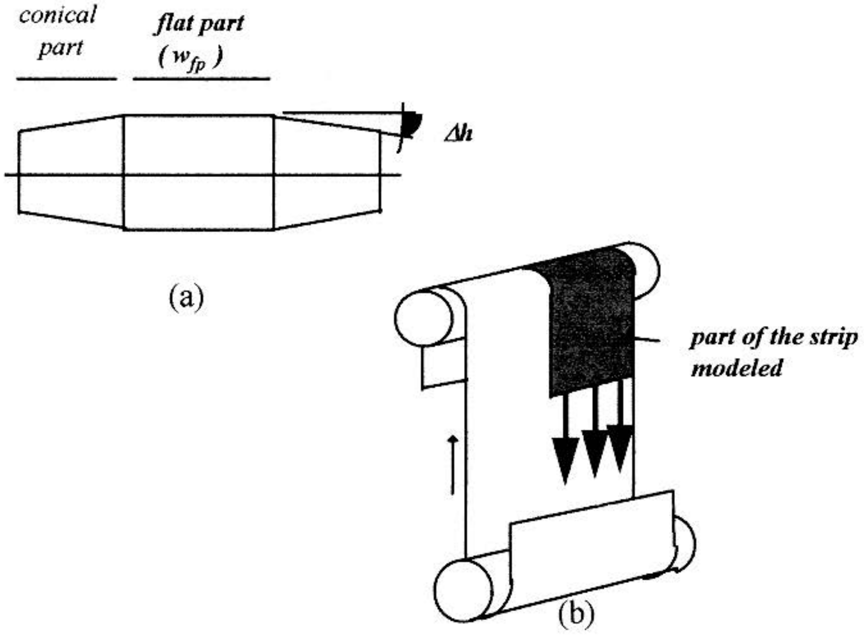


Figure 3 : geometry of the roll and part of the strip modeled.

	FEM		***Simplified Model***	
σt (Mpa)	***Lc (mm)***	***Δσx max (Mpa)***	***Lc (mm)***	***Δσx max (Mpa)***
7.51	720	14	760	13
15	856	25	880	23
22.5	930	35	964	32
30	1000	44	1032	40.9

Table 1: comparison between FEM calculation and simplified model with K 1= 1.5 (W = 1100 mm ; t = 1.5 mm ; W_{fp} = 400 mm ; Δh = 1 mm). Δσxmax is the difference of the machine stresses between the center of the roll and the edges of the strip.

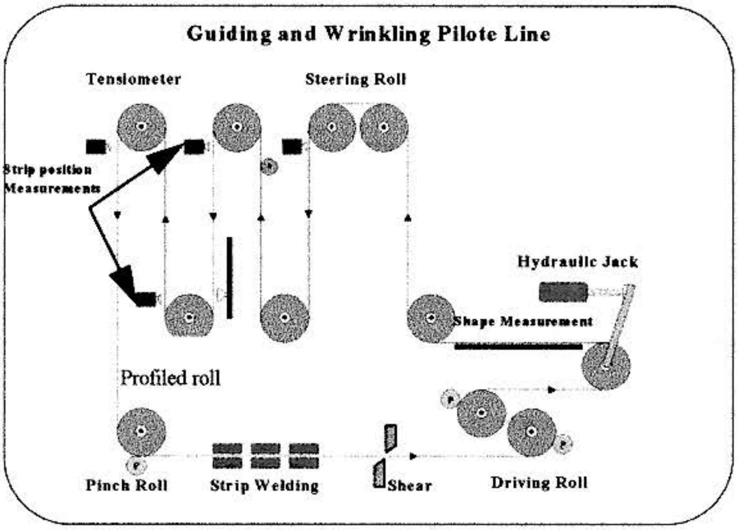


Figure 4 : Irsid pilot line (span length : 7.2 m, roll diameter 800 mm, max speed 1000 m/mn, max width 1600 mm, max thickness 1mm, equiped with one steering guide ; strip position measurement before and after the profiled roll).

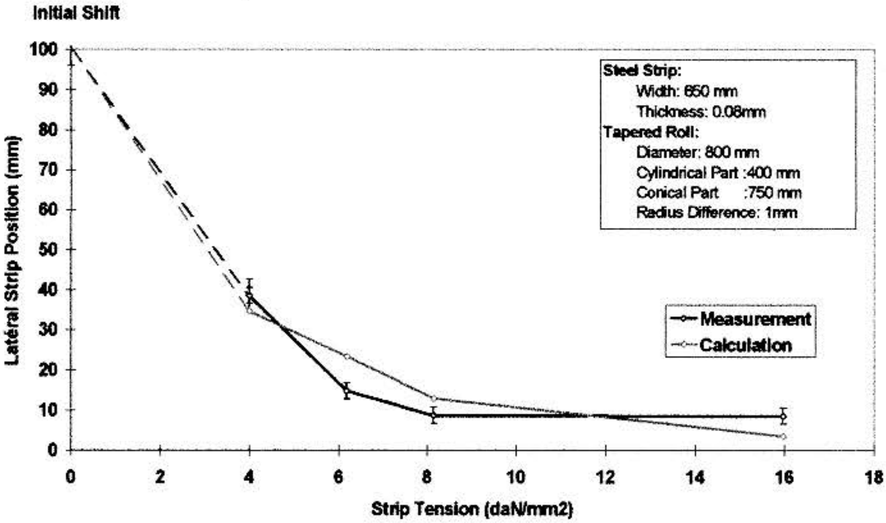


Figure 5 : strip position measurement after the profiled roll after an initial shift y0 of 100 mm.

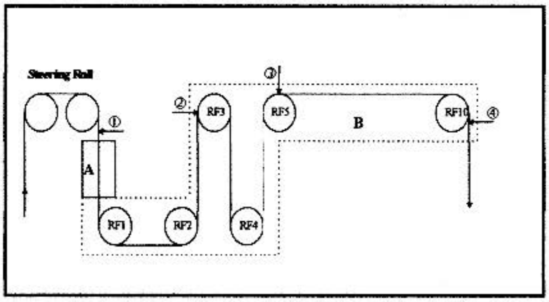


Figure 6 : CRM low scale continuous annealing line (max strip width : 300 mm ; max speed : 70 mm).

Roll	*Flat part (mm)*	*Taper (mm)*	*Span length (m)*
RF1	50	1.8	5.7
RF2	50	1.8	2.0
RF3	100	1.3	5.1
RF4	50	1.8	5.1
RF5	50	1.8	5.1
RF10	50	1.8	12.8

Table 2 : roll and span characteristics for CRM pilot line ; all rolls have a diameter of 750 mm and a total width of 350 mm.

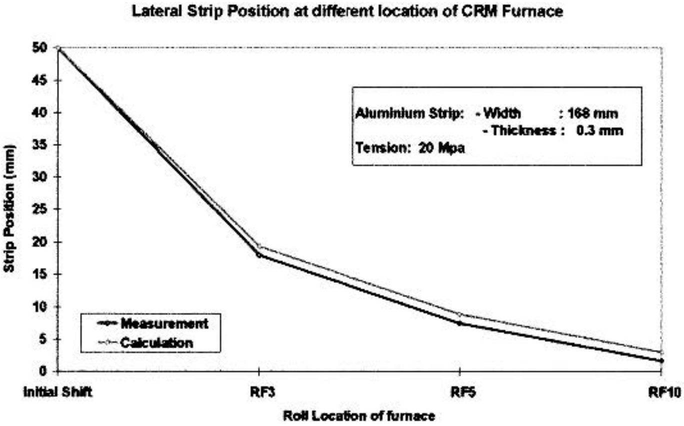
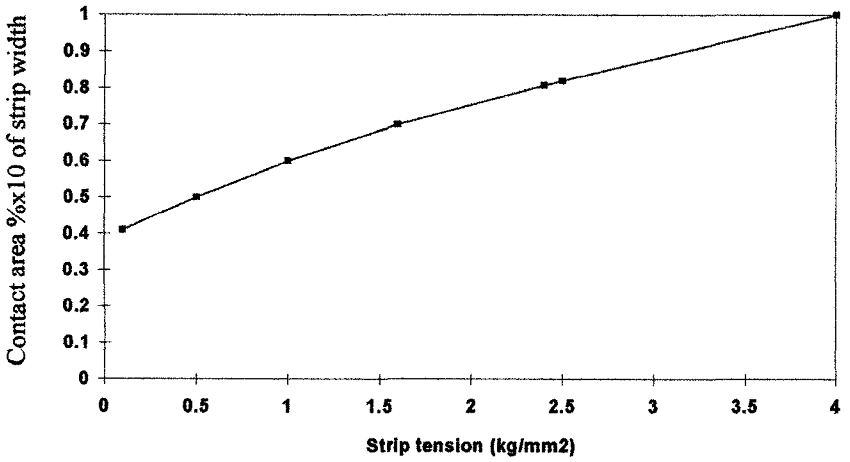


Figure 7 : measurement centering effet of different profiled rolls (RF3, RF5 and RF10).The strip has an initial shift of 50 mm.



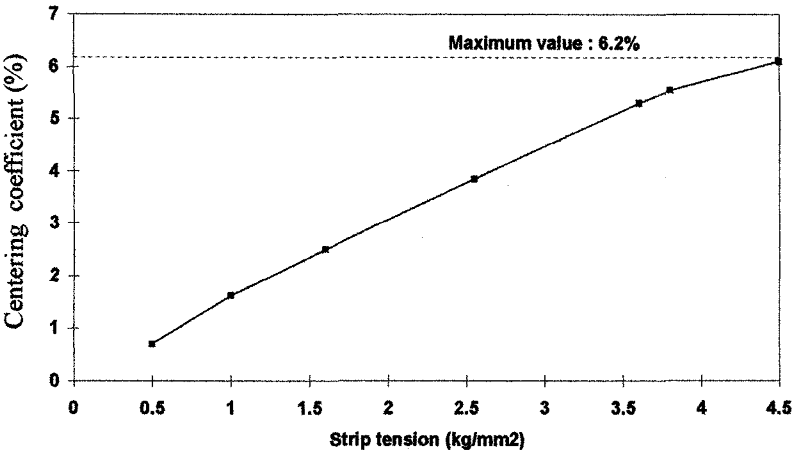


Figure 8 : effect of the tension on the contact area and the centering coefficient. The centering coefficient reaches the maximal value of 6.2 % when full contact is achieved between the roll and the strip (aluminium strip : t =0.4 mm ; W = 1000 mm ;Roll : W_{fp} = 400 mm ; Δh = 1 mm).

F. Onno, J. C. Petit
Measurement and Prediction of the Centering Effect of a Crowned Roll on Steel Strips
6/8/99 Session 3 11:15 - 11:40 a.m.

Question – Wolfermann, Technical University of Munich
What about the bending moment if your strip goes on the roll compared with the tension in your strip? Can it be neglected?

Answer – F. Onno, Sollac Florange
In the work presented, the boundary movement and other factors was neglected, particularly in the span module and you see from the measurement that the results were correct enough to do some improvements on the lines. Typically, for these applications, you don't need to know if the centering effect will be 3 or 3.2% but you need to know if the centering effect is 3, 0 or 20%. And the measurements show that the model is accurate enough.

Question – Rolfe Bosse, Munich
Do you have any web aligning devices in these machines?

Answer – F. Onno, Sollac Florange
Yes.

Question:
What do you mean by steering rolls?

Answer – F. Onno, Sollac Florange
A steering roll and a web guide roll are the same thing. You cannot build a line without steering rolls. But steering rolls are not our business. When we need a steering role we just buy it. Take for instance we can have six steering roles in one continuous line but still we have over 200 other rolls which are not guided. So the question is what do you do with the 200 other rolls?

Question – Jim Dobbs, 3M
Do you have a large coefficient of friction or traction between your web and your rollers?

Answer - F. Onno, Sollac Florange
Yes, you see, in the lines you completely bend the strip. The angle of wrap is 80 degrees commonly.

Question- John Shelton, Oklahoma State University
In your measurements, did you have a rather straight strip? Or did you have noticeable camber in it and if you had camber, did you have a problem with it? Running it off-center toward the, that is uncentering it because of having contact on one side and not a balanced force

Answer - F. Onno, Sollac Florange
Yes. The model and the experimental results exhibit the camber problem. We attempt to reduce our camber and then really if we can do nothing maybe we can decide to buy a new steering role. In a plant, you have to make this kind of decisions.

Question- John Shelton, Oklahoma State University
The steel industry is the industry that has lateral problems. They have long spans and low strain and lateral behavior is a severe problem in the steel industry, lesser in the aluminum industry with a third the elasticity I would say. Would you agree?

Answer – F. Onno, Sollac Florange
Yes.