ANALYSIS OF WIDTH DEVIATIONS OF STAINLESS STEEL STRIPS THROUGH THE SLITTING PROCESS

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Precise stainless steel strips – (very) thin and (very) narrow – are metallurgical products that are increasingly in demand in today's market, due to the many different end-uses in a variety of fields. There has been exponential development in the number of final applications with special requirements regarding the properties of such bands, including width tolerance range even tighter than those normally recommended by specific standards. The paper refers to the capability of the slitting process regarding width precision of stainless steel strips and depends on several factors: the thickness of the processed material, the number of strips obtained from the same pass, the rigidity of the processed material - shear system.

Keywords: process capability, slitting process, stainless steel strip, precise slitter

1. Introduction

This paper is part of a broader research project that has as its main objective the determination of the possibilities for improving the properties of (very) thin, precise stainless steel strips for applications obtained via drawing and welding processes. This paper is focused on the width deviation of the aforementioned strips after slitting operations.

The width of the blank and some shape characteristics of stainless steel strips are essentially determined during the slitting process, where the band is slited using a circular shear. In these circumstances, as it stands, stainless steel strips also have the properties of a precise products because of their width tolerances. The latest technological processes require values for width tolerances that are very narrow. Thus, the effective design and construction of the 'mother' and 'father' parts of the shear are very important for achieving the width prescribed tolerances (*Fig. 1*).

The shear scheme is designed purely to obtain a strip width that fits within a default range of tolerance. This range of tolerance is usually quite broad, and does not take into general account the distribution of width values obtained over time when the same type of material (or any material part of the same class, type and/or size) is processed. The research has had the primary endpoint to reducing

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the total width of tolerance ranges comparing to precise specified tolerances in the specific standard product, *SR EN ISO 9445-1(2)/2010*[1].

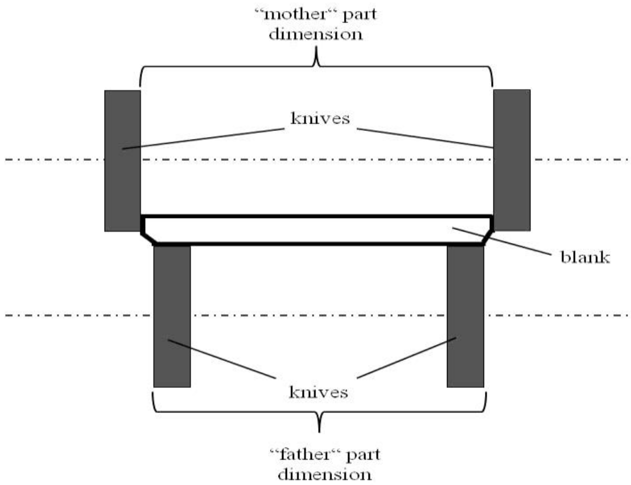


Fig.1 – The materialization of the strip width during the slitting process

Technologically, the slitting process capability regarding the strips width determined for a certain type of product (within prescribed width tolerance limits) is an incomplete capability. This interpretation is based on the quantification of process capability in relation to a reference dimension of shear (the 'mother'), thus moving the data centre to the values 'targeted' during production. Knowing this variation, it is possible to define the rules governing the expression of process capability of such a process differently. Knowledge of this variation, accordingly, is a very useful way to anticipate the possibility of developing improved products, which will in turn facilitate future analysis and improvement.

2. Experimental study

2.1. Materials used

After the slitting process, strips (coils) are obtained that are narrower than the input and the resulting product is defined by: width (the main dimension of the process), fractured edge quality, the strip (coil) aspect after slitting and the absence of shape defects[2]. The slitting can be considered an art, but at the current time is being treated as a science[3]. During slitting, many factors (mainly technological parameters) contribute to the quality of the cut. It is very important to know how to "read the width deviation", as this interpretation can provide us important details about what is not right in the process equation.

The investigated material is flat, cold rolled and heat treated semi-finished, surfaces type : *2D*, *2B* (according to *BS EN 10088/2005, ASTM A 480/2011, ASTM A 666/2010, DIN 17441/1997, JIS G 4305/2001*), *2R* (according to *BS EN 10088/2005, DIN 17441/1997*), *BA* (according to *ASTM A 480/2011, ASTM A 666/2010*)[4].

These surface types are correlated to processing type on process flow, Fig. 2, where :

- black coil is the hot rolled coil (raw material)
- *APH* - furnace (production line) for hot annealing and pickling process
- *ZM* - Sendzimir rolling mill for cold rolling process
- *APC* – furnace (production line) for cold annealing and pickling process
- *SKP* – skin pass production line for skin passing process
- *DG* – degreasing production line for degreasing process
- *BAL* – furnace (production line) for bright annealing process
- *2H* – surface type proper for hard material, according to *BS EN 10088/2005*
- *BA "mirror" – 2R/BA* surfaces type after skin passing process
- *1F* - surface type proper for soft material, according to *BS EN 10088/2005*

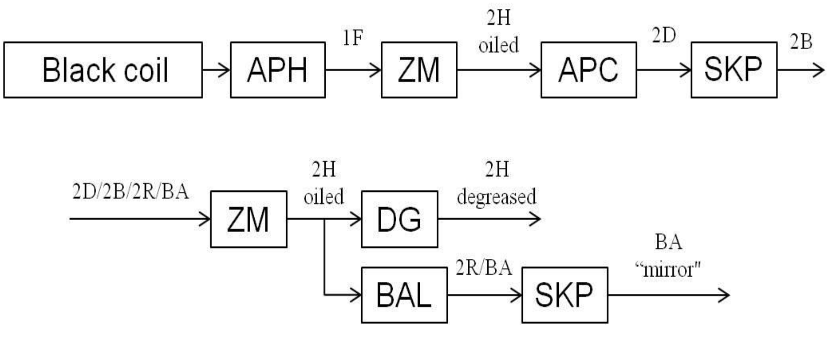


Fig.2 – Technological flows for obtaining different types of surfaces

The chemical composition of AISI defined by the steel grades, austenitic and ferrite is : 304, 304DL, 305, 305DL, 306DL, 307DL, 308DL, 309, 309S, 316, 316L, 316Ti, 321, 430.

Studies and research were performed on two types of slitting line:

- a narrow slitting line, with the possibility of processing strips with entry width (330÷650) mm, exit width (5÷650) mm and thickness (0.05÷0.8) mm;

- a wide slitting line, with the possibility of processing strips with entry width (400÷1300) mm, exit width (30÷1300) mm and thickness (0.1÷1.5) mm.

The shear was prepared according to the two schemes shown in *Fig. 3* (*Fig. 3.a*: strips processing with final width > approx. 15 mm; *Fig. 3.b*: strips processing with final width < approx. 15 mm).

The latest generation production lines ensure high standards of product quality and productivity achievements. It used lopper after the slitter and, regarding the type of shear, circular knives, rubber and thin metal spacers. This type of processing line is often used for the precise slitting of (very) thin and stainless steel strips.

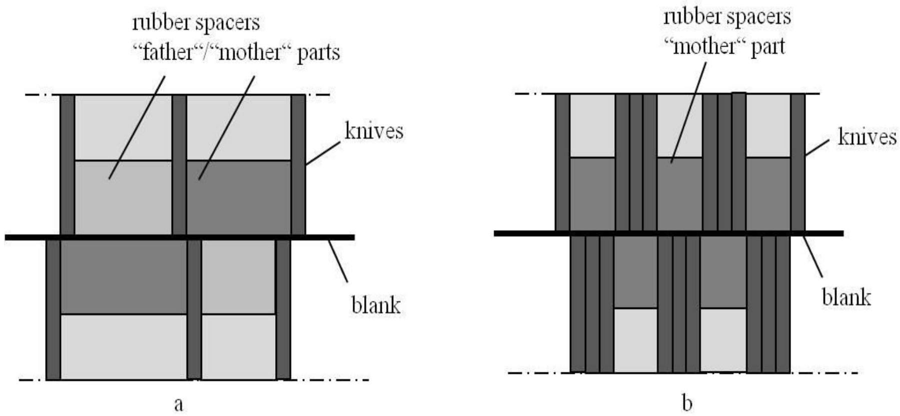


Fig.3 – Shear scheme[5]

2.2. Experimental data collection

During the experimental research, there were performed width measurements and recorded their values. There were used the primary data (continuous type) obtained through observation to achieve analytical determination of the width value. Compliance with technological disciplines of measurement and the recording of data was ensured exclusively by a same person. The measurements (strips width) were performed with digital calipers (measurement accuracy - 0.01 mm). To ensure the accuracy of our measurements and to avoid the incursion of other measurement errors into our data, always have been used the same calipers for the same dimensional range: (0÷150) mm, (150÷300) mm, (300÷800) mm, (800÷1000) mm.

Measurements of width were achieved corresponding to the two parts of the coils (*"top end"* and *"bottom end"*) according to standard SR EN ISO 9445-1(2)/2010 [1]. The digital calipers were tested from a metrological point of view and MSA (Measurement Systems Analysis), being the period of metrology validity[6][7].

2.3. Data analysis and interpretation of results

2.3.1. Analysis of strips width deviations depending on their thickness

Analysis of the width deviations of the stainless steel strips obtained by the slitting process was carried out according to specific ranges of thickness. For narrow slitter lines, these deviations are shown in *Fig. 4* (a÷d).

The process was identically repeated to examine the wide slitting line, *Figs. 5* (a, b) and *Fig. 6*.

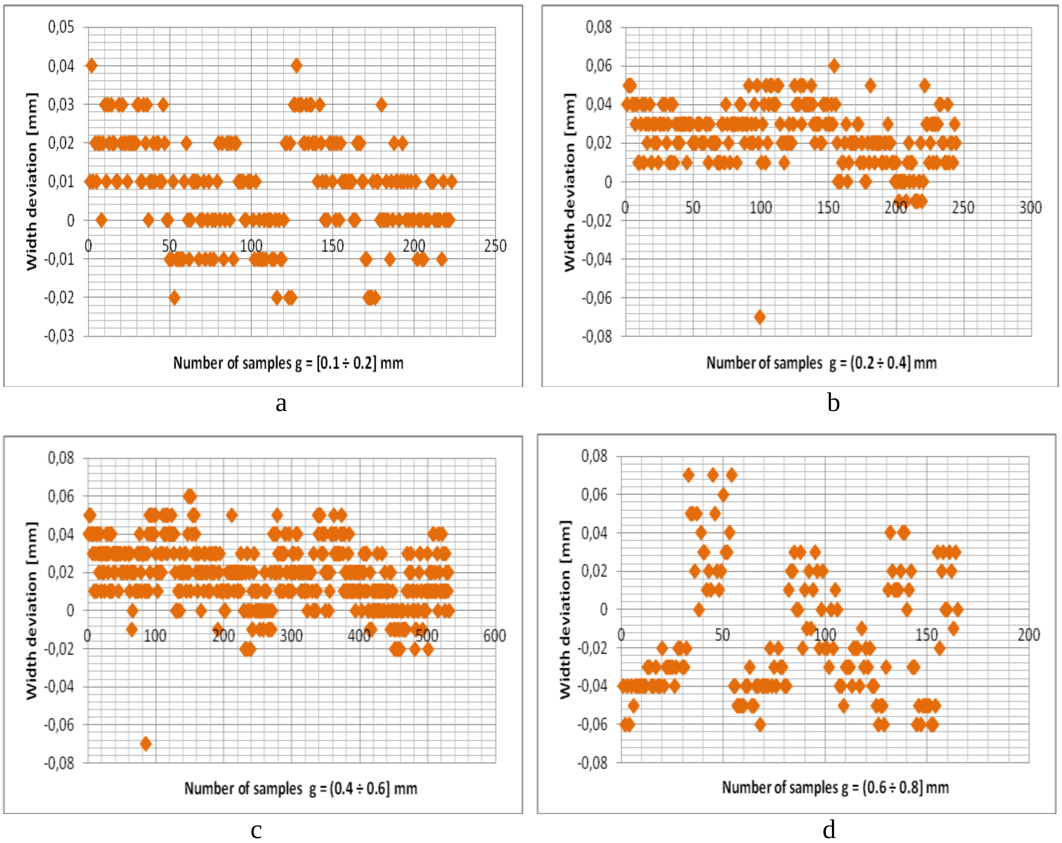
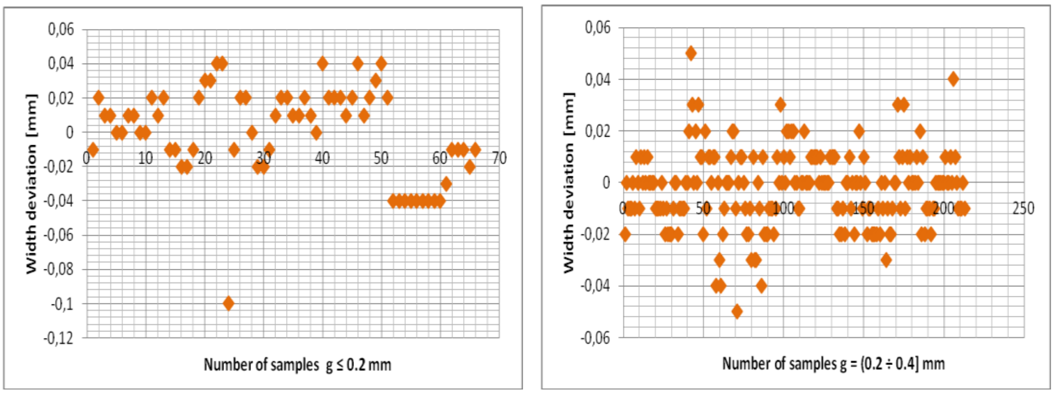
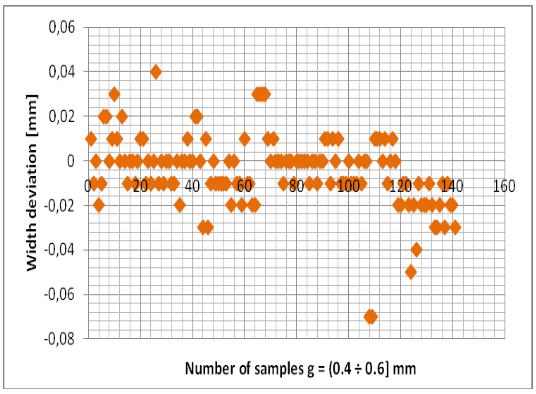


Fig.4 – Width deviations depending on the thickness of material (narrow slitting line)



a b

Fig.5 – Width deviations depending on the thickness of material (wide slitting line)



c

Fig.6 – Width deviations depending on the thickness of material (wide slitting line)

The case of narrow slitting line : if for the first three analyzed thickness intervals, after the removal of the outliers, the total range of width deviations values is within 0.07 mm, for the fourth thickness range examined, the total range of deviations values from the width is within 0.13 mm.

The case of wide slitting line : if for the first two analyzed thickness intervals, after the removal of the outliers, the total range of deviations values from the width is within 0.08 mm, for the third examined thickness interval, the total range of deviations values from the width is within 0.1 mm.

2.3.2. Analysis of strips width deviations obtained from the same coil

By analyzing variations in width (the values of which are summarized in *tables 1 and 2*) of the samples corresponding to each coil I found maximum width deviations up to 0.07 mm on both slitting lines.

The maximum deviations being recorded on the coils with the largest thickness from the analyzed intervals are shown in *Fig. 7* (narrow slitting line) and *Fig. 8* (wide slitting line).

For the analysis of more significant width deviations for thicker blank products, below it was represent deviation of width in the samples taken from the same coil for thickness interval of (0.6÷0.8] mm (narrow slitting line, *Fig. 9*) and (0.4 ÷ 0.6] mm (wide slitting line, *Fig. 10*).

Examination of these data shows averages of the values for total ranges of deviations within 0.03 mm for the narrow slitting line and within 0.02 mm in the case of the wide slitting line. From this, we can conclude that there are no significant changes in the size of deviations ranges when comparing the deviations ranges of products manufactured on different slitting lines (extreme values, one for each slitting line, it were excluded).

Table 1: **Width deviations of the samples (narrow slitting line)**

Coil no.	Lower limit [mm]	Upper limit [mm]	Total range [mm]
1	0.02	0.05	0.03
2	0.02	0.04	0.02
3	0.01	0.01	0.00
4	0.00	0.04	0.04
5	0.01	0.03	0.02
6	-0.01	0.00	0.01
7	0.01	0.04	0.03
8	0.01	0.03	0.02
9	-0.06	-0.04	0.02
10	-0.05	-0.02	0.03
11	-0.04	-0.01	0.03
12	0.02	0.05	0.03
13	-0.06	-0.02	0.04
14	0.00	0.07	0.07
15	0.01	0.07	0.06
16	-0.07	0.04	0.11
17	0.02	0.05	0.03
18	0.00	0.04	0.04
19	0.00	0.04	0.04
20	0.01	0.03	0.02
21	0.03	0.05	0.02

Table 2: **Width deviations of the samples (wide slitting line)**

Coil no.	Lower limit [mm]	Upper limit [mm]	Total range [mm]
1	-0.04	-0.04	0.00
2	0.00	0.02	0.02
3	0.00	0.01	0.01
4	-0.04	-0.02	0.02
5	-0.02	0.01	0.03
6	-0.04	-0.03	0.01
7	0.03	0.03	0.00
8	0.02	0.03	0.01
9	-0.02	0.00	0.02
10	-0.02	0.02	0.04
11	0.00	0.00	0.00
12	0.00	0.03	0.03
13	-0.02	0.01	0.03
14	-0.01	0.02	0.03
15	-0.01	0.01	0.02
16	-0.01	0.02	0.03
19	-0.01	0.04	0.05
20	0.00	0.02	0.02
21	-0.01	0.00	0.01
23	-0.03	0.00	0.03
24	0.02	0.02	0.00

Table 1: **Width deviations of the samples (narrow slitting line) continuation -**

Coil no.	Lower limit [mm]	Upper limit [mm]	Total range [mm]
22	0.03	0.05	0.02
23	0.01	0.04	0.03
24	0.02	0.06	0.04
25	0.00	0.04	0.04
27	0.00	0.04	0.04
28	0.01	0.06	0.05
30	-0.06	-0.03	0.03
31	0.00	0.04	0.04
32	-0.01	0.01	0.02
35	0.00	0.03	0.03
36	0.01	0.03	0.02
37	-0.01	0.03	0.04
38	0.00	0.03	0.03
39	-0.01	0.05	0.06
40	0.02	0.02	0.00
42	0.00	0.03	0.03
43	0.00	0.03	0.03
44	-0.02	0.02	0.04
45	-0.06	-0.02	0.04
46	-0.02	0.03	0.05
48	0.00	0.03	0.03
49	-0.02	0.02	0.04
50	-0.01	0.03	0.04
51	-0.02	0.02	0.04
52	-0.02	0.01	0.03
53	-0.02	0.03	0.05
54	-0.02	0.03	0.05
55	-0.03	0.03	0.06
56	0.01	0.04	0.03
57	0.01	0.04	0.03
58	-0.01	0.01	0.02
59	0.00	0.05	0.05
60	0.00	0.04	0.04
61	-0.01	0.03	0.04
62	0.00	0.02	0.02
63	-0.01	0.01	0.02
65	-0.02	0.02	0.04

Table 2: **Width deviations of the samples (wide slitting line)** - - continuation -

Coil no.	Lower limit [mm]	Upper limit [mm]	Total range [mm]
25	-0.02	-0.01	0.01
28	0.01	0.04	0.03
29	0.05	0.05	0.00
30	-0.07	-0.07	0.00
32	0.01	0.04	0.03
35	-0.01	0.01	0.02
36	0.02	0.02	0.00
37	-0.01	0.03	0.04
38	-0.02	0.02	0.04
39	-0.04	-0.02	0.02
40	-0.04	0.00	0.04
43	-0.04	-0.01	0.03
45	-0.05	0.02	0.07
46	-0.02	0.00	0.02
47	-0.03	0.01	0.04
48	-0.04	0.00	0.04
50	-0.02	0.01	0.03
51	0.00	0.03	0.03
52	0.00	0.04	0.04
53	0.02	0.04	0.02
57	-0.10	-0.01	0.09
59	0.02	0.02	0.00
60	-0.02	0.02	0.04
61	-0.01	-0.01	0.00
62	-0.05	0.02	0.07
63	-0.03	0.01	0.04
64	-0.01	0.00	0.01
66	-0.03	0.00	0.03
67	-0.02	0.00	0.02

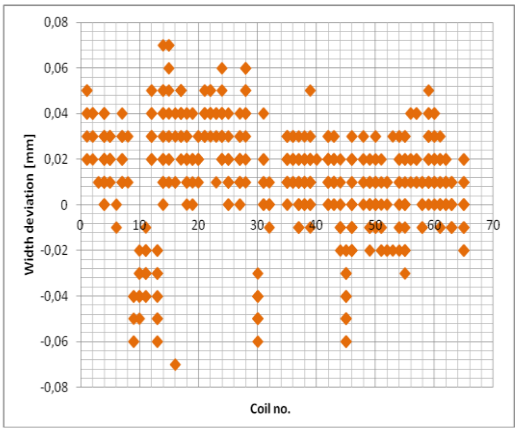


Fig.7 – Samples width deviations (narrow slitting line)

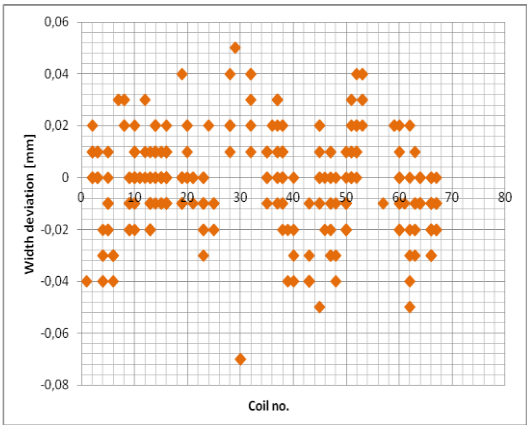


Fig.8 – Samples width deviations (wide slitting line)

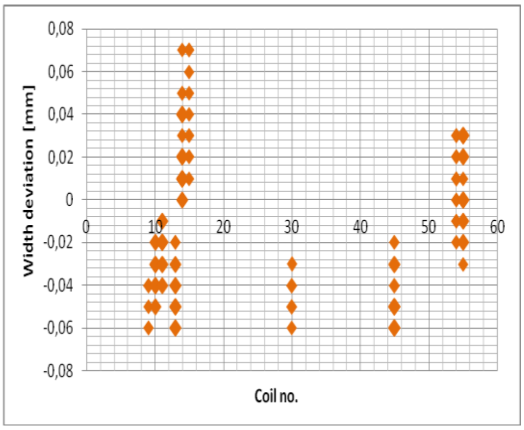


Fig.9 – Width deviations for thickness interval (0.6÷0.8] mm (narrow slitting line)

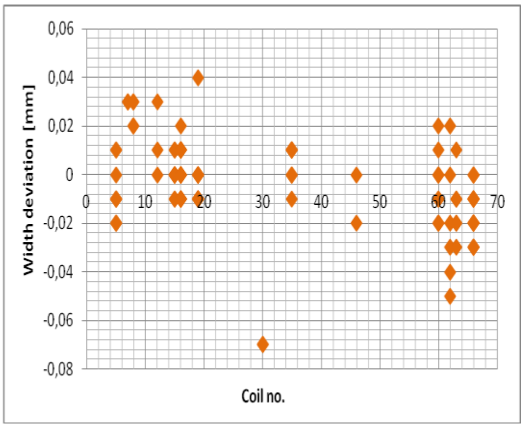


Fig.10 - Width deviation for thickness interva (0.4÷0.6] mm (wide slitting line)

In the first case, they were recorded sizes of width deviations range between (0.02÷0.07) mm and in the second case (0÷0.07) mm. For these thickness intervals of strips, greater ranges of width deviations are generated by the cumulative records from different coils processed in conditions that are not identical.

2.3.3. Analysis of strips width deviations according to the number of strips through the same passing

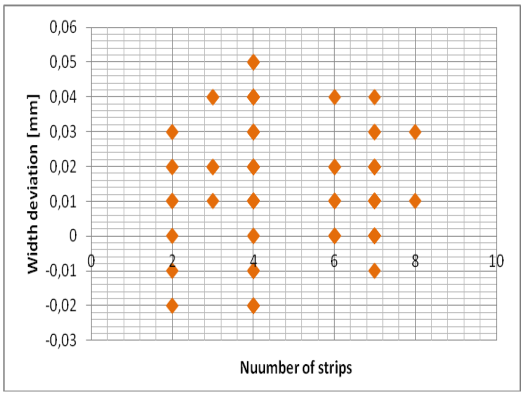
It was conducted a comparison between measurements of the widths of the samples, depending on the number of strips obtained at the same pass processing.

For the narrow slitting line, these are shown in *Fig. 11* (a÷d) :

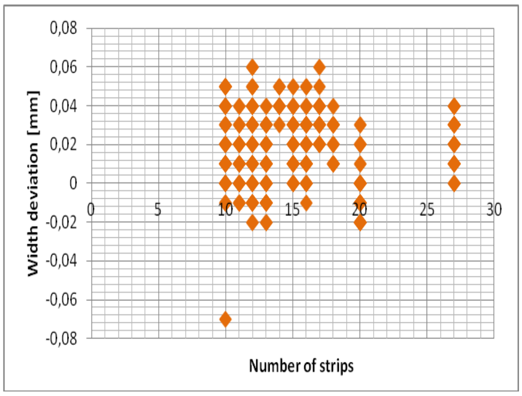
- thickness range ≤ 0.6 mm - maximum 9 strips, respectively (10÷27) strips;
- thickness range (0.6 ÷ 0.8] mm - 8 strips, respectively (10÷16) strips.

For the wide slitting line, these are shown in *Fig. 12* (a÷d) :

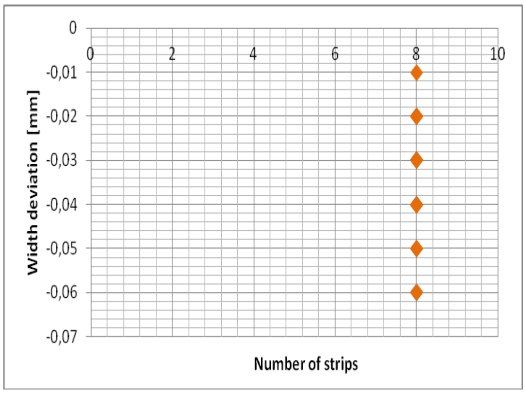
- thickness range ≤ 0.4 mm - maximum 10 strips, respectively (10÷13) strips;
- thickness range (0.4 ÷ 0.6] mm - maximum 6 strips, respectively (7÷15) strips.



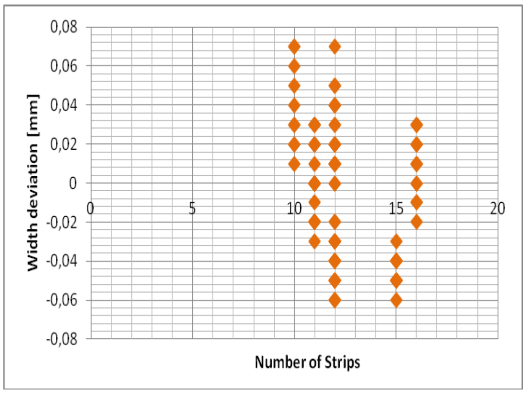
a – total range of variation 0.07 mm
(-0.02÷0.05) mm



b – total range of variation 0.08 mm
(-0.02÷0.06) mm - without singular value



c - total range of variation 0.05 mm
(-0.06÷0.01) mm

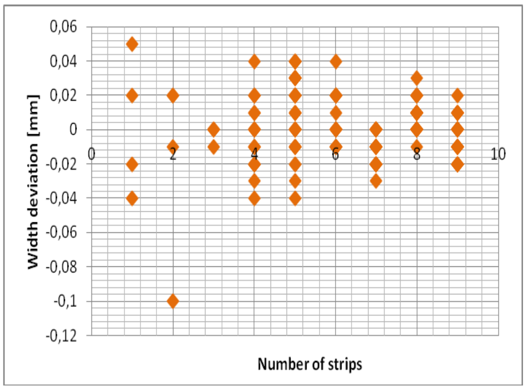


d - total range of variation 0.13 mm
(-0.06÷0.07) mm

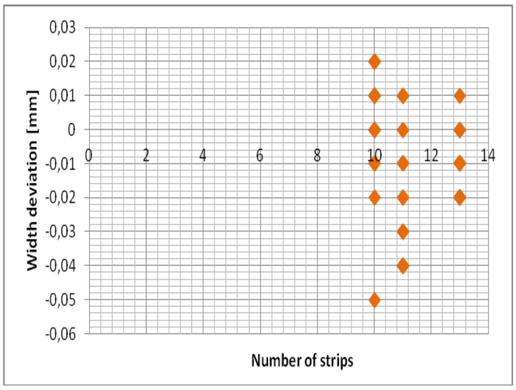
Fig.11 – Influence of strips number/shear on width precision (narrow slitting line)

It is notworthy that the number of strips obtained at the same pass affects the width precision strips only for processed material thickness (0.6÷0.8] mm, range applies only to narrow slitting line. For the lower thickness ranges, deviations do not have significant differences in width, depending on the number of strips obtained from the same pass process.

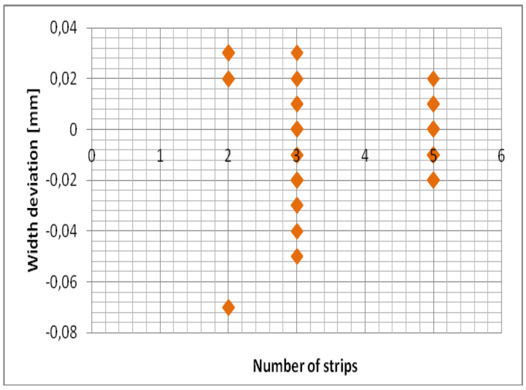
The range of thickness (0.6÷0.8] mm shows larger deviations in width, in conjunction with the big number of strips obtained at the same pass processing, it is actually for narrow slitting line the thickness interval located at the end thickness range of thickness [0.05÷0.8] mm for which the shear was designed.



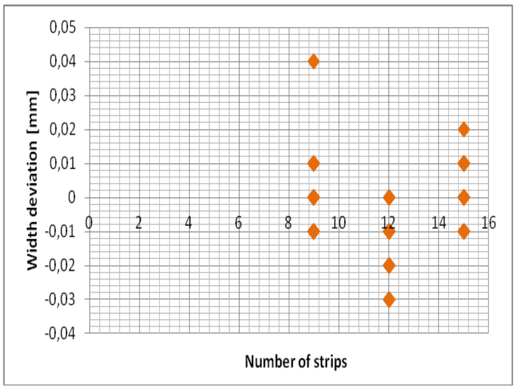
a – variation total range 0.09 mm-w/o sing. value



b – total range of variation 0.07 mm



c – variation total range 0.08 mm-w/o sing. value



d – variation total range 0.07 mm

Fig.12 – Influence of strips number/shear on width precision (wide slitting line)

3. Conclusions

The research define a way of determining the slitting process capability regarding width of precise stainless steel strips. This capability is related to the size of the ‘mother’ part, which thus permits the analysis of new products and improvement of the manufacturing process of products of a type already in broad use.

It was noted that there are no significant changes in the size of deviation ranges when comparing the deviation ranges of products manufactured on different slitting lines. Width deviations in strips obtained from the same coil are much lower in comparison to total deviations range registered during the processing of the same strips from different coils. This is due to the identical conditions of processing, primarily in terms of the shear creation process. The big number of strips (10÷16) obtained from the same processing in conjunction with the thicker blank (0.6÷0.8] mm has a negative influence regarding the width precision and the fractured edges quality of stainless steel strips, when the analyzed thickness range represents upper thickness interval for which the shear was designed (the case of the narrow slitting line).

By increasing the thickness of the processed material, and also, by increasing the number of the strips for the same passing, the width deviations were mainly in negative values, that means they migrate to the ‘father’ part dimension of the shear without any width deviations under this dimension being registered. The phenomenon can be explained by the loss of rigidity in the material processed-shear system (i.e. the elastic deformations of shear axes because of the high radial forces arising during the process). In order to improve the width slitting process capability and fractured zone, the future potential research could be about : rethinking of the shear design process to ensure the same stiffness when processing all types and sizes of material contained in the technical specification and rethinking of rubber spacers diameters to reduce the shear radial forces.

R E F E R E N C E S

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