NEW METHODOLOGY FOR THE CALCULATION OF AN ANGLE ROLL PASS DESIGN*

José Aparecido Pereira[1]

Abstract

The innovative methodology developed by the author allows the elaboration of an Angle Roll Pass Design based on the practical observations of the rolling process and applies mathematical criteria, using the Ekelund´s formula supported by Advanced Excel tools (Reach Goal, PROCV-PROCH, Macros) and AutoCad. The first step is the definition of the number of stands, roll dimensions, gear boxes reduction, initial stock, average reductions, spread factors, finishing speed and type of grooves. For each pass are calculated: bite angle, spread, section reduction, lost and gain of temperature, separating force, speed, torque and motor power. After these calculations and checking of the parameters, the program calculates the dimensions of the passes transforming the flat passes into shaped ones. With these dimensions it is possible to draw the grooves using AutoCad and check section reductions. This methodology was already used for the development of a new project and also to check the parameters of existing ones, with comparison of the results and has shown to be reliable in real and tested projects. It is an innovative process that is not available in known literature.

Keywords: Angle; Pass design; Ekelund

1. *Mechanical Engineer, Consultant, J. A. Pereira Consultoria de Engenharia, Vila Velha, ES, Brasil.*

1 INTRODUCTION

In the known literature, there is no clear and well defined methodology for the calculation of angle roll pass design. Many projects are executed based on analogy with existing projects or simply copying designs from one plant to another. Nowadays those who hold this technology are mainly the suppliers of rolling equipment that have their own methods of calculation and these methods are not available to customers because they are part of their know how.
In this paper a calculation methodology based on the Ekelund's formula is presented. This method is feasible since the angles can be treated as flat passes using differentiated spread factors. Pereira [1] discussed this subject at ABM Week Seminar in 2016. As previously shown, the spread factors presents wide variation depending on the rolling conditions, the geometry of the grooves, the degree of free spread in the groove and the set-up of the guiding system among others.
There are enormous variety of dimensions of angles, with linear mass from 0.5kg/m (1/2"x1/8") up to 58kg/m (8"x3/4"). Depending on the angle dimensions and the technical characteristics of the rolling mill, angles may be rolled from two to eleven passes.
Currently there are at least four types of roll pass designs:

- Butterfly with curve legs;
- Butterfly with straight legs;
- Butterfly with Intermediate edger pass;
- Butterfly with opened grooves.

Besides these types there are special roll pass designs.
.

2 MATERIAL AND METHODS

2.1 MAIN MENU

The program has a Main Menu that allows access to all Excel worksheet tabs that contain: Data entry, Tables, Calculations and Graphs (Figure 1).

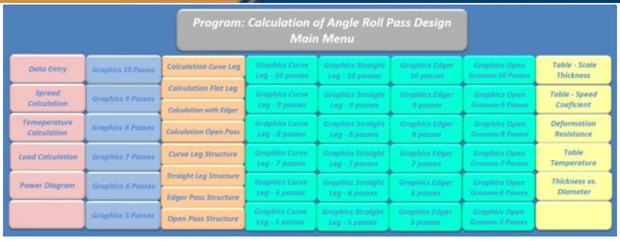

Figure 1. Main Menu

2.1.1 DATA ENTRY

In the Data Entry, technical values of the rolling mill are entered such as: dimensions of the angle and initial stock, temperature, velocity, chemical composition, groove friction factors, spread factor and thickness of the passes, among others. For the thickness reduction of the passes, the program suggests a value that may or may not change according to the results of the calculations (Figure 2).

Rolling Mill and Process Data										
Description		P1	P2	P3	P4	P5	P6	P7	P8	P9
Motor Power - kW		600	600	600	600	600	600	600	600	600
Motor Basic Rotation - RPM		500	500	500	500	500	500	500	500	500
Motor Max. Rotation - RPM		1400	1400	1400	1400	1400	1400	1400	1400	1400
Gear Box Reduction		25,000	20,000	17,000	13,000	9,000	6,000	5,000	4,000	3,000
Diameter - mm		420	420	420	420	420	420	420	420	420
Roll type		0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8
Distance Between Stands - m		4,0	4,0	4,0	4,0	10,0	4,0	4,0	4,0	4,0
Motor Max. Torque - kg.m		11,5	11,5	11,5	11,5	11,5	11,5	11,5	11,5	11,5
		286,5	229,2	194,8	149,0	103,1	68,8	57,3	45,8	34,4
Leg Length - mm	85,00	Number of Passes			9	% Carbide			0,17	
Leg Thickness - mm	7,00	Type of Grooves			CA	% Manganese			0,60	
Internal Radius - mm	8,00	Initial Temperature - ºC			1000	% Crome			0,00	
Initial Section Tickness - mm	75	Scale Thickness - mm			0,032	Hardness Factor			1,00	
Initial Section Width - mm	129	Initial Speed - m/s			0,5	Billet Dimensions - m/mm			12	160
Groove Friction		1,30	1,30	1,30	1,30	1,30	1,30	1,30	1,45	1,3
Spread Factor		1,30	1,55	1,80	2,05	2,30	2,55	2,80	3,05	6,00
Thickness Factor		0,700	0,718	0,735	0,753	0,770	0,788	0,805	0,823	0,840
Suggested Thickness - mm	75,0	52,5	37,7	27,7	20,8	16,0	12,6	10,2	8,4	7,0
Choosed Thickness - mm	75,0	52,5	37,7	27,7	20,8	16,0	12,6	10,2	8,4	7,0
Roll Gap - mm		6,0	6,0	6,0	5,0	5,0	5,0	4,0	4,0	4,0

Figure 2. Entry data

Below is shown more details of this Entry Data for an Angle 85x7mm (Figure 3).

Description		P1	P2	P3	P4
Motor Power - kW		600	600	600	600
Motor Basic Rotation - RPM		500	500	500	500
Motor Max. Rotation - RPM		1400	1400	1400	1400
Gear Box Reduction		25,000	20,000	17,000	13,000
Diameter - mm		420	420	420	420
Roll type		0,8	0,8	0,8	0,8
Distance Between Stands - m		4,0	4,0	4,0	4,0
Motor Max. Torque - kg.m		11,5	11,5	11,5	11,5
		286,5	229,2	194,8	149,0
Leg Length - mm	85,00	Number of Passes			9
Leg Thickness - mm	7,00	Type of Grooves			CA
Internal Radius - mm	8,00	Initial Temperature - ºC			1000
Initial Section Tickness - mm	75	Scale Thickness - mm			0,032
Initial Section Width - mm	129	Initial Speed - m/s			0,5
Groove Friction		1,30	1,30	1,30	1,30
Spread Factor		1,30	1,55	1,80	2,05
Thickness Factor		0,700	0,718	0,735	0,753
Suggested Thickness - mm	75,0	52,5	37,7	27,7	20,8
Choosed Thickness - mm	75,0	52,5	37,7	27,7	20,8
Roll Gap - mm		6,0	6,0	6,0	5,0

Figure 3. Details of Entry Data

2.1.2 CALCULATIONS AS FLAT PASSES

2.1.2.1 SPREAD CALCULATION

Ekelund's formula has a complex resolution, since the variable B1 (exit width) is found on both sides of the equation (Figure 4).

$$\boxed{B1} = \sqrt{8 \times A \times Ld \times \Delta H - 4 \times A \times Ld \times (H0 + H1) \times ln\frac{\boxed{B1}}{B0} + B0^2}$$

$$A = \frac{1.6 \times \mu \times \sqrt{R \times \Delta H} - 1.2 \times \Delta H}{H0 + H1}$$

Figure 4. Ekelund´s Formula

An Excel spreadsheet was developed with special tools such as Reach the Goal and Macros which is able to find the width of the rolled pass (B1) and the other calculations of all the passes in few seconds. Details in green (Figure 5)

Description		P1	P2	P3	P4
Entry Thickness	75	75,0	52,5	37,7	27,7
Entry Width	129	129,0	136,4	143,6	149,8
Exit Thickness		52,5	37,7	27,7	20,8
Exit Width - Ekelund		134,7	141,0	147,0	152,3
Spread Factor		1,30	1,55	1,80	2,05
Temperature		1000	990	981	973
Spread Ekelund		5,68	4,63	3,46	2,48
Aditional Width		136,4	143,6	149,8	154,9
Section	9675	7160	5412	4149	3221
Section Reduction		26,0	24,4	23,3	22,4
Height Reduction		22,5	14,8	10,0	6,9
Work Diameter		373,5	388,3	398,3	404,2
Contact Arc Projection		64,8	53,6	44,6	37,3
Friction Coeficient		0,44	0,44	0,45	0,45
Speed		0,50	0,66	0,86	1,11
Speed Factor		1,00	1,00	1,00	1,00
Maximum Bite Angle		23,8	23,9	24,1	24,3
Bite Angle		20,0	15,9	12,9	10,6
Bite Condition		Bite	Bite	Bite	Bite

Figure 5. Spreadsheet for width calculation

At the same time with the dimensions of the input initial stock and other data, it is calculated the length of the angle leg. If the length is different from the entry data value, you need to change the dimensions of the initial stock until the planned value is reached (Figure 6).

Calculated Cold Leg Lenght-mm	85,0

Figure 6. Dimension of the cold leg

2.1.2.2 LOADS CALCULATION

With the value of the spread calculation it is calculated the separating rolling force, torque and power of the pass. These loads are calculated according to the methods of Siebel and Ekelund and with alterations introduced by SMS, both methods are empirical [2] [3] (Figure 7).

	P1	P2	P3	P4
Speed	0,50	0,66	0,86	1,11
Groove Friction	1,30	1,30	1,30	1,30
Temperature	1000	990	981	973
Reduction	22,5	14,8	10,0	6,9
	30,0	28,2	26,5	24,9
Work Diameter	373,5	388,3	398,3	404,2
Thickness/Diameter	20,00	13,50	9,50	7,00
Contact Arc	64,8	53,6	44,6	37,3
Contact Section	8841	7695	6684	5783
Resistance by Table	12,50	12,97	13,54	14,32
Relative Speed	1,34	1,70	2,17	2,75
Speed Coeficient	1,08	1,14	1,14	1,20
Total Resistance	17,5	19,2	20,0	22,3
Roll Force - Siebel - ton	155,1	147,6	133,9	128,8
Roll Pressure	7160	5412	4149	3221
	716	541	415	322
	7160	5410	4140	3220
	1,000	1,005	1,015	1,023
Chemical Composition - T	8,68	8,90	9,11	9,33
Viscosity Constant - n	0,040	0,041	0,042	0,043
	8,00	8,20	8,37	8,55
Mofified Speed - v´	500	661	863	1111
Mofified Visc. Coef. - v´	8,11	8,36	8,62	8,91
Friction Coeficient	0,55	0,55	0,56	0,56
Projected Contact Area - X1	8.601	7.503	6.545	5.688
Rolling Conditions - X2	1,24	1,33	1,43	1,52
Material Strength - X3	8,73	8,98	9,24	9,51
Force - SMS/Ekelund - ton	138,8	134,7	131,0	126,1

Figure 7. Roll force by Siebel and Ekelund

As there are some small differences between the methods, mainly in the first and last passes, in this paper it is calculated the average between the value of the methods (Figure 8).

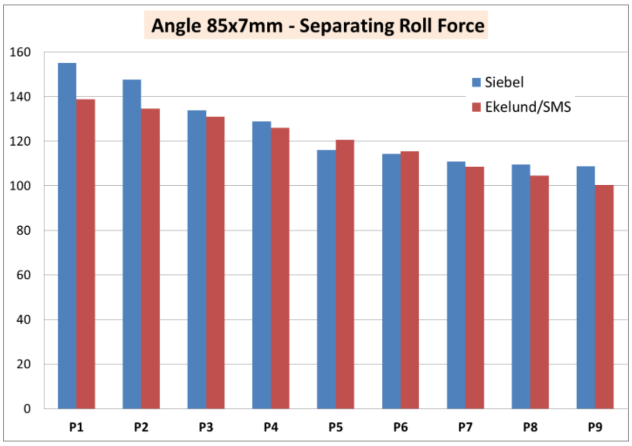

Figure 8. Results by Siebel and Ekelund

2.1.2.3 TEMPERATURE CALCULATION

According to SMS [2] for the calculation of the temperature in the rolling process the following results are considered:

• Temperature loss by conduction heat from the stock to the rolls;

• Temperature gain due to mechanical deformation;

• Temperature loss through the heat radiation of the rolled stock in the path between one pass and another.

The loss of heat by the contact of the cooling water with the stock can be considered negligible according to the SMS, since the volume of water is small [2]

During the pass it is calculated the sum of the loss by conduction and the gain by deformation. This new temperature at the bar output is the initial reference to calculate the radiation temperature loss until the next pass (Figure 9).

	Description	P1	P2	P3	P4	P5	P6	P7	P8	P9
	Bar Flow Rate	3580015	3580015	3580015	3580015	3580015	3580015	3580015	3580015	3580015
	Work Diameter	373,5	388,3	398,3	404,2	409,0	412,4	413,8	415,6	417,0
	Contact Length	64,8	53,6	44,6	37,3	31,3	26,5	22,3	19,3	17,1
	Scale Thickness	0,0320	0,0320	0,0320	0,0320	0,0320	0,0320	0,0320	0,0320	0,0320
	Contact Time	0,1296	0,0810	0,0517	0,0336	0,0222	0,0151	0,0104	0,0075	0,0056
	Conduction Value	0,000016	0,000017	0,000021	0,000025	0,000028	0,000037	0,000035	0,000034	0,000033
	Specific Heat	781,54	778,31	775,45	772,55	769,77	763,78	761,09	758,91	757,12
	Bar Density	7,55E-06	7,55E-06	7,56E-06	7,56E-06	7,57E-06	7,58E-06	7,58E-06	7,58E-06	7,59E-06
	Temperature Loss - Conduction	12,2	11,3	12,1	12,4	11,9	13,4	10,8	9,2	7,9
	New Temperature - Conduction	988	979	969	960	952	932	927	922	917
	Roll Force - kN	1520	1447	1312	1262	1138	1120	1087	1074	1066
	Deformation Resistance	176,7	192,8	200,5	221,9	231,5	263,9	299,6	337,2	374,4
	Equivalent Resistance	0,30	0,28	0,27	0,25	0,24	0,22	0,20	0,18	0,17
	Bar Density	7,66E-06	7,66E-06	7,66E-06	7,66E-06	7,66E-06	7,66E-06	7,67E-06	7,67E-06	7,67E-06
	Temperature Loss - Deformation	9,0	9,2	9,1	9,6	9,4	10,0	10,3	10,8	11,0
	New Temperature - Cond + Deform	998	989	980	971	963	944	937	932	927
Step 1	Emission Factor	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8
	Radiation Factor	5,7E-06	5,7E-06	5,7E-06	5,7E-06	5,7E-06	5,7E-06	5,7E-06	5,7E-06	5,7E-06
	Bar Temperature - K	1271	1262	1253	1244	1236	1217	1210	1205	1200
	Enviroment Temperature - K	303	303	303	303	303	303	303	303	303
	Stock Dimension	94	91	89	88	87	87	87	87	87
	Pass Distance	4,0	4,0	4,0	4,0	10,0	4,0	4,0	4,0	4,0
	Radiation Time	8,0	6,0	4,6	3,6	7,1	2,3	1,9	1,6	1,3
	Time Interval	1,6	1,2	0,9	0,7	1,4	0,5	0,4	0,3	0,3
	Bar Perimeter	378	363	355	351	350	349	348	348	349
	Temperature Loss	1,67	1,56	1,49	1,44	3,49	1,32	1,29	1,27	1,26
	New Temperature - ºC	997	988	978	970	959	943	936	930	926

Figure 9. Temperature loss and gain calculation by conduction and deformation.

During the path from one pass to another the temperature gradually decreases, so this distance is divided into five steps [2] and in each step there is a new temperature and the respective loss and so on for all the passes (Figure 10).

Step	Parameter				
Step 1	Emission Factor	0,8	0,8	0,8	0,8
	Radiation Factor	5,7E-06	5,7E-06	5,7E-06	5,7E-06
	Bar Temperature - K	1271	1262	1253	1244
	Enviroment Temperature - K	303	303	303	303
	Stock Dimension	94	91	89	88
	Pass Distance	4,0	4,0	4,0	4,0
	Radiation Time	8,0	6,0	4,6	3,6
	Time Interval	1,6	1,2	0,9	0,7
	Bar Perimeter	378	363	355	351
	Temperature Loss	1,67	1,56	1,49	1,44
	New Temperature - ºC	997	988	978	970
Step 2	Temperature Loss	1,66	1,55	1,48	1,43
	New Temperature - ºC	995	986	977	968
Step 3	Temperature Loss	1,65	1,54	1,47	1,42
	New Temperature - ºC	993	984	975	967
Step 4	Temperature Loss	1,64	1,54	1,47	1,42
	New Temperature - ºC	992	983	974	965
Step 5	Temperature Loss	1,63	1,53	1,46	1,41
	New Temperature - ºC	990	981	973	964
	Total Radiation Loss	**8,2**	**7,7**	**7,4**	**7,1**

Figure 10. Temperature radiation loss in five steps

2.1.2.4 TEMPERATURE LOSS /GAIN

It can be observed that the radiation loss is high in pass 5 due to a large distance between the stands (10 m) (Figures 11 and 12).

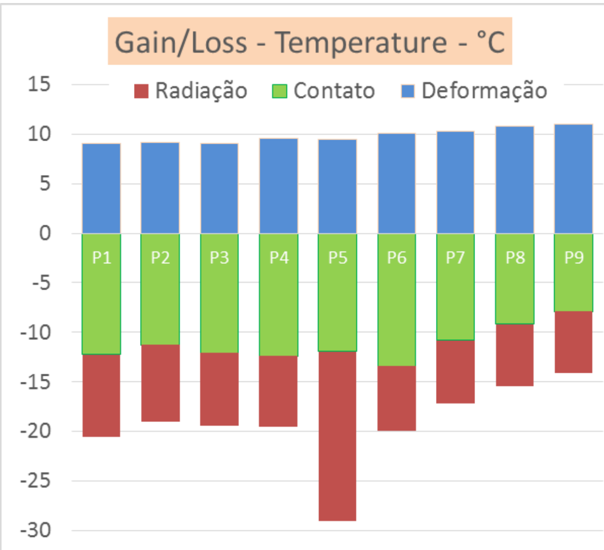

Figure 11. Gains and Losses by passes

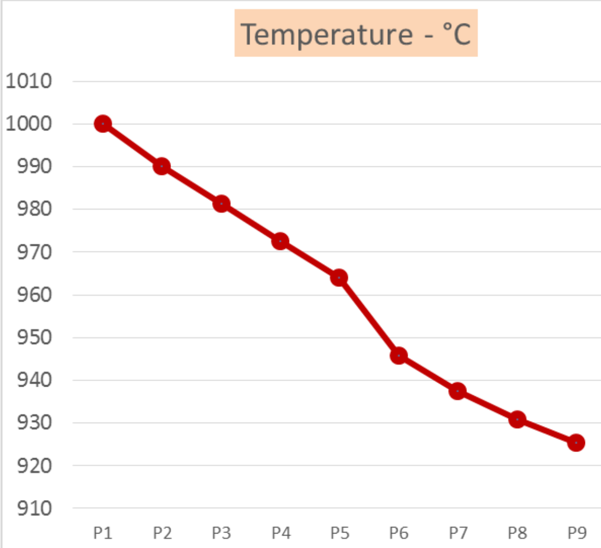

Figure 12. Evolution of temperature along the rolling mill

2.1.2.5 GRAPH RESULTS

Eight graphs show the final results of the calculations and then it is possible to observe if any parameter isn't in accordance to the desired values.
The rolling deformation resistance graph shows the table values and the additional ones due to the various factors related to the rolling with grooves (Figure 13).

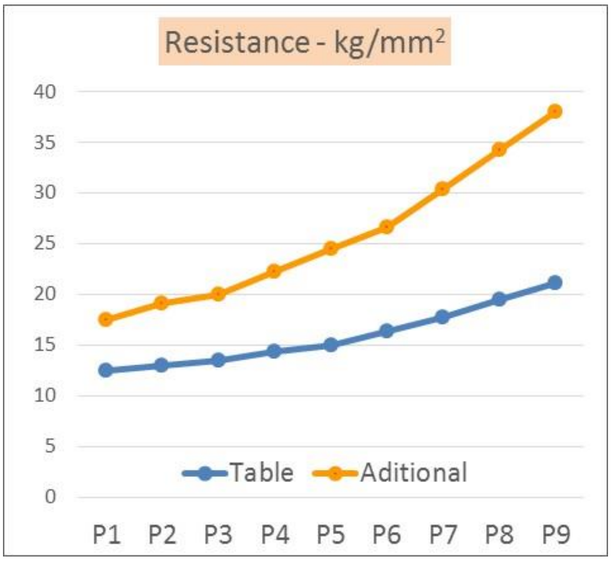

Figure 13. Rolling deformation resistance

The largest spreads happen in the first passes due to the higher section reductions (Figure 14)

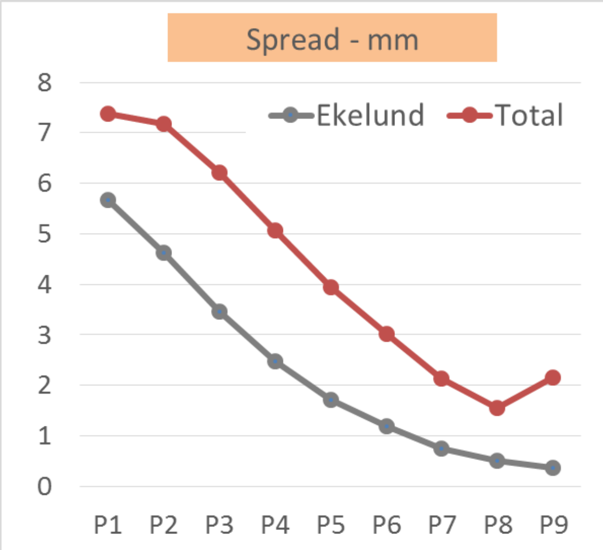

Figure 14. Spread by pass

The section reductions decrease in the direction of the finishing stands, which is ideal for reducing the wear of the finishing grooves. Average reduction (21%) is at a good value (Figure 15).

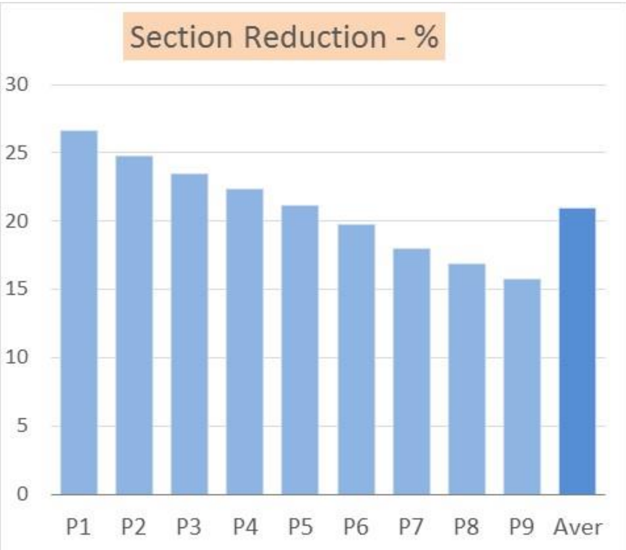

Figure 15. Section Reduction

All the calculated bite angles are below the maximum (Figure 16)

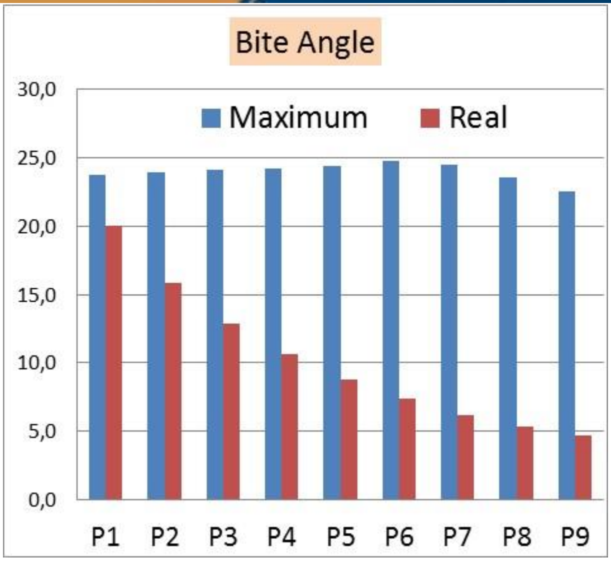

Figure 16. Bite angle – Maximum and Real

The value of the roll separating forces are decreasing what is good to prevent roll breakages (Figure 17).

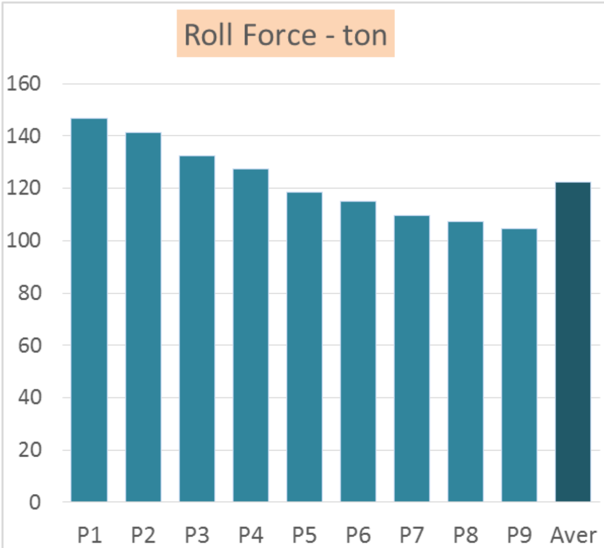

Figure 17. Roll separating forces

The calculated torque is below maximum and decreasing in the direction of the finishing stands (Figure 18).

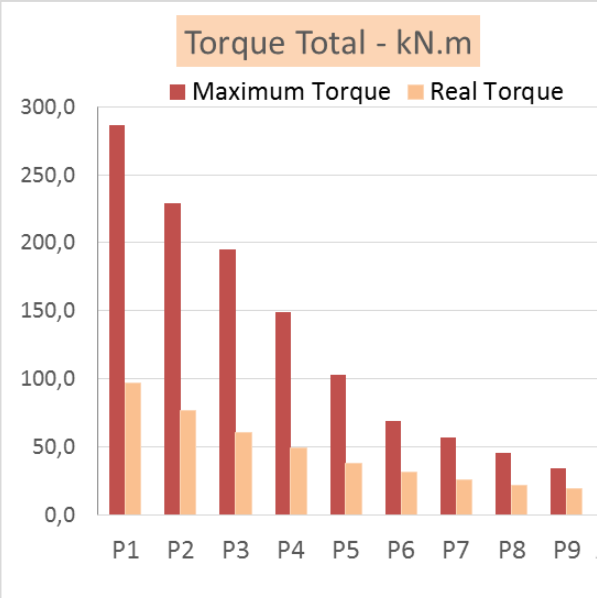

Figure 18. Torque - Maximum/Real

The motor power is similar in all the passes below the maximum (Figure 19).

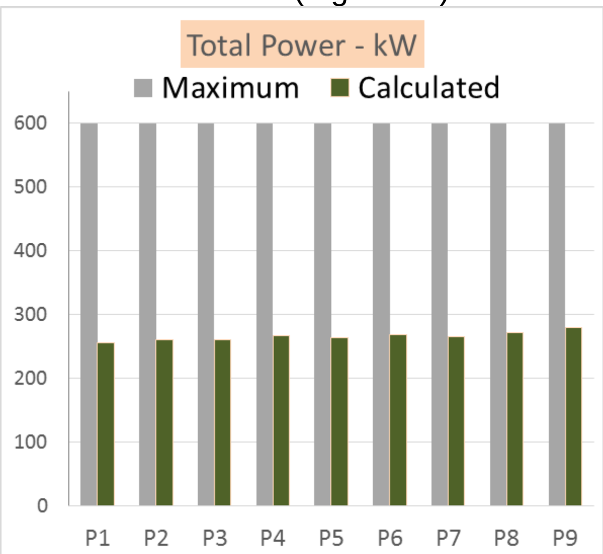

Figure 19. Motor Power

Although the power of the motor is below the maximum, it is necessary to examine it by checking its position in relation to the motor power diagram, especially when the motor is working at low rotations.
In this case the powers are below the power diagram of the motor (Figure 20)

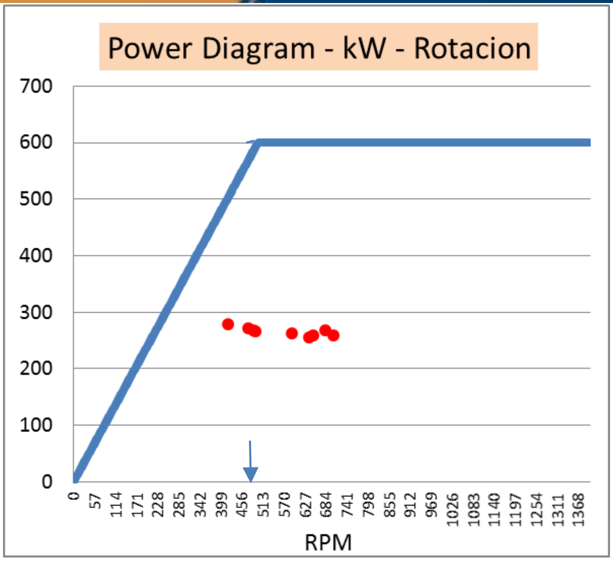

Figure 20. Motor power diagram vs. calculated power motor base rotation

2.1.3 CALCULATIONS AS SHAPED PASSES

Up to this step all the calculations were done as flat passes only including some factors for calculation of spread and roll force. Now these flats passes must be transformed into shaped passes following concepts connected to pre-established parameters.

2.1.3.1 DEFINITIONS OF THE GROOVE PARAMETERS AND CALCULATIONS

In this paper is shown the roll pass design with the curve leg.
The grooves are designed in accordance to a structure that will be like a skeleton.
This structure is formed by the following parameters that initially will define the dimension and shape of the Average Fiber [3] [4] (in blue).

- AF – Average Fiber;
- VA – Vertex Angle;
- SS – Straight Stretch
- LR – Leg Radius
- MR – Mean Radius
- GT – Groove Thickness
- VR – Vertex Radius
- IR – Internal Radius
- EA – Extremity Angle
- ER – Extremity Radius

(Figure 21).

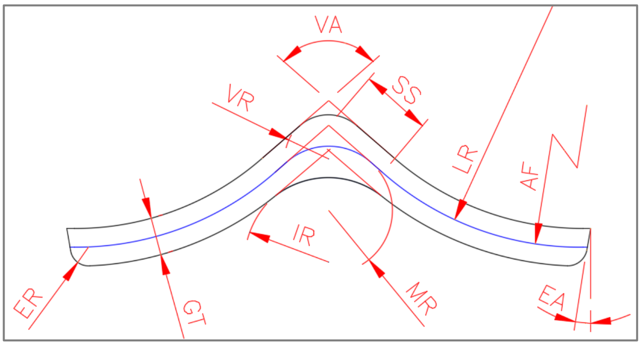

Figure 21. Structure of an angle groove

The length of the Average Fiber is equal to the width of the Flat Pass. All the other parameters are defined in accordance to the number of passes and position in the mill. These parameters are defined by the values taken in the graphs (Figure 22).

It may be observed that all the parameters represented in the graphs have a progressive evolution without abrupt changes in value.

Based on this parameters the program calculate the **Groove Thickness in order to have the same section of the Flat Pass.**

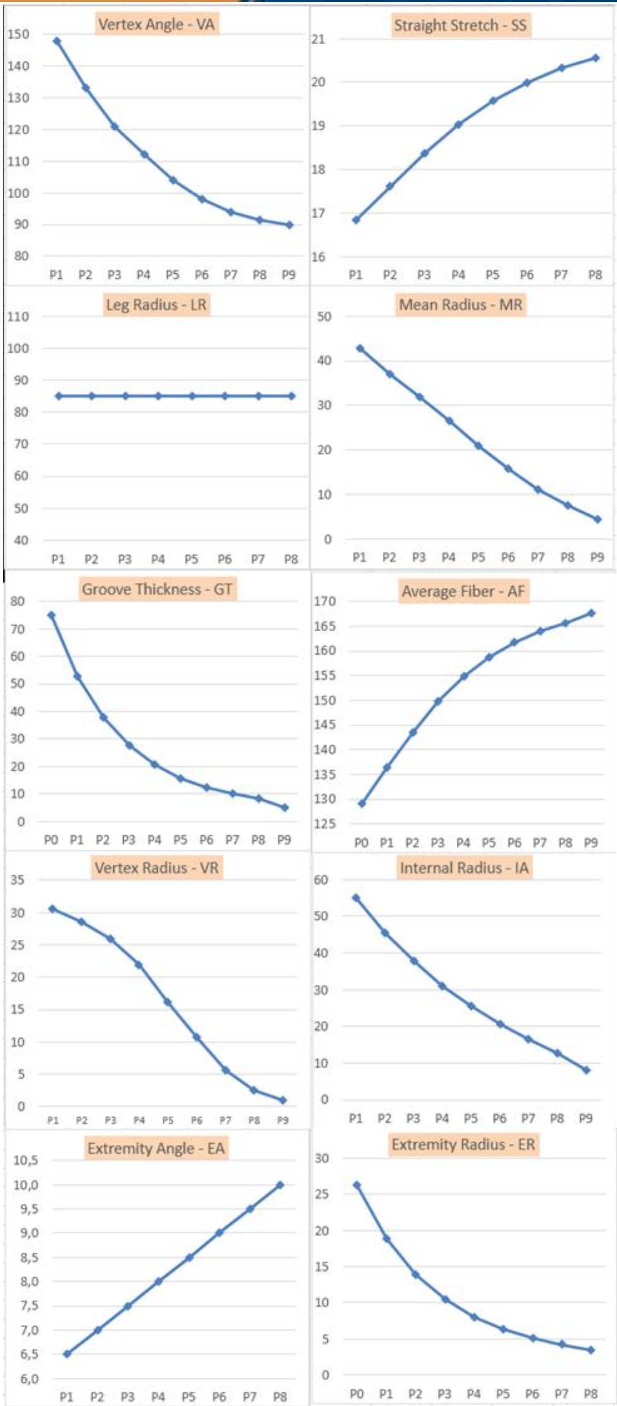

Figure 22. Groove structure parameters

2.1.3.2 DRAWING THE GROOVE WITH AUTOCAD

Based on the calculated and established parameters, the grooves are drawn with AutoCad (Figure 23).

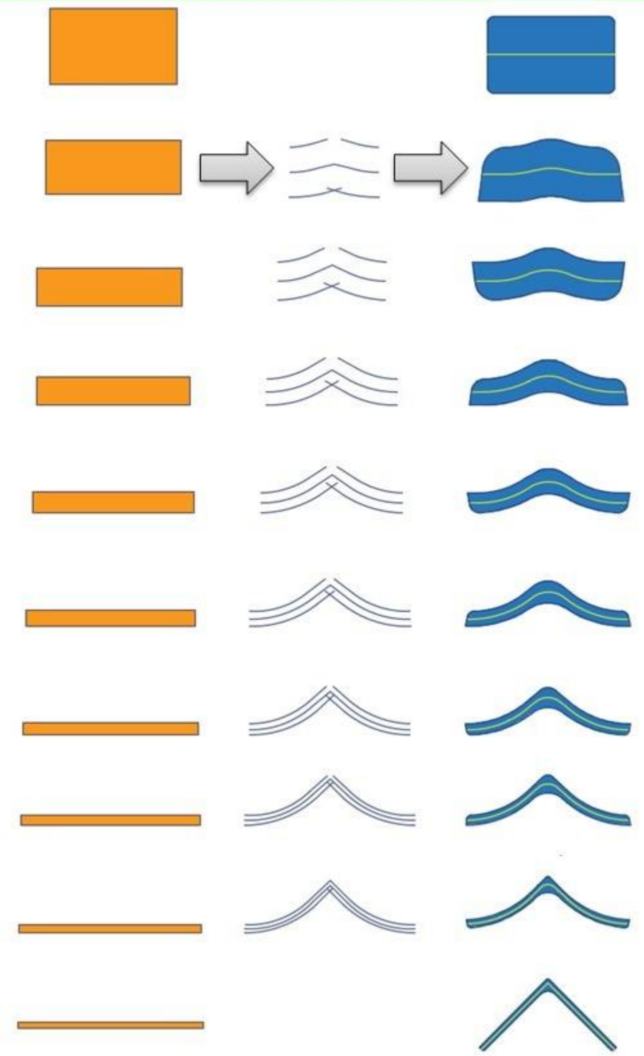

Figure 23. Transformation of Flat Pass to Shaped passes by AutoCad.

The sections of the grooves are calculated and compared with the values previously calculated by the Program Excel.

3 RESULTS AND DISCUSSION

An example of this comparison is shown in the following graphs, showing very close results with difference calculated (Excel) and drawn (AutoCad) below 2.5% (Figure 24).

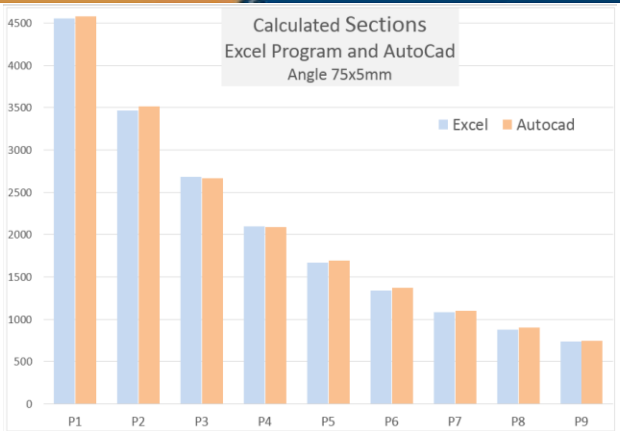

Figure 24. Excel and AutoCad sections

The methodology was already used in two customer projects: The first one for a 3" angle pass design with 5 leg thickness and the second one a 5" angle pass design with 3 leg thickness, both at the technical limit of the rolling mill.
For the success of the project it were developed roll pass designs with low sections reductions in order to have low loads. It was also a success obtaining products within the tolerance soon in the initial tests and low loads in the rolling mill.

4 CONCLUSION

The applied methodology proved to be fully feasible, and the treating of the angles as flat passes generated reliable results. The calculation of the loads and the rolling temperature resulted in values comparable to data from other projects and practical results collected in the tests in other plants.

REFERENCES

1 José Aparecido Pereira. Determination and application of spread coefficient of angles using Ekelund's formula. ABM Week. 2016.
2 SMS. Manual Roll Pass Design Training. 1991-95. Dusseldorf.
3 Mário José de Oliveira Ferraz. Calibração de Produtos Não-Planos. ABM. 1977.
4 Dietmar Kosak. Calibração de Produtos Não-Planos. ABM. 1977.