Optimization of withdrawing cylinder at vertical continuous casting of steel using CAD and CAE

M. Tufoi, I. Vela, C. Marta, D. Amariei, A.I. Tuta and C. Mituletu

Abstract**—**In this work is presented an optimization method of correcting cylinder-withdrawal to the withdrawal of the semi-finished steel to vertical continuous casting plant of steel. Optimizing cylinders was achieved by: use of statistical calculations applied to quantities, experimental measurements obtained directly from the withdrawal of blanks, using techniques CAD (Computer Aided Design) and CAE (Computer Aided Engineering) design, modeling and optimization of cylinders; using finite element method, FEM for static and dynamic simulations, the behavior of withdrawal-straightening rolls in continuous casting process for determining stress, strain and displacement that occur in this process. The studies is both experimental and theoretical, and aims to improve the process of withdrawal of the semi continuous casting with vertical curvilinear wire of steel, using modern methods of analysis, design and optimization of mechanical drives. The study has as a result in a pair of cylinders practical realization of withdrawal, multiple-ray machines, able to withdraw more dimensions of round profile. This is an advantage in that, to change the diameter of semi-products withdrawn, no is necessary to change withdrawal cylinders.

Keywords**—** CAD, CAE, continuous casting, cylinder, FEM, optimization

I. Introduction

CONTINUOUS casting of metals is a process for obtaining metal blanks directly from molten metal in the form of wires, billets, blooms, tubes of different sizes. The process consists in introducing molten metal into a crystallizer (mold) externally cooled with water. In crystallizer occurs the partial solidification (at surface) of the metal. This, under metal-static pressure, left the crystallizer, and is taken by a straightening-pull mechanism that helps to extract blank. The blank is then subjected to a secondary cooling in order to complete solidification. Then there is the blank cutting to length desired by the customer, and evacuation of the production flow, quality control department towards. Continuous casting of metals and especially for steel is a technique increasingly used both nationally and globally, because it has major advantages compared with conventional casting of steel profiles. Thus, upgrading and optimization of continuous casting process, including installation of withdrawal of the semi-finished profiles of metals is an intense focus of research in the field [1], [2], [3].

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II. Theoretical Considerations

A. Continuous casting machine

The authors propose an optimization of the withdrawal rolls of continuous casting plant of low-alloy steel pipe used to obtain. Installation is a vertical continuous casting plant with curvilinear wire and equipped with four-planer stands withdrawal. Layout is shown in fig. 1.a. and 1.b.

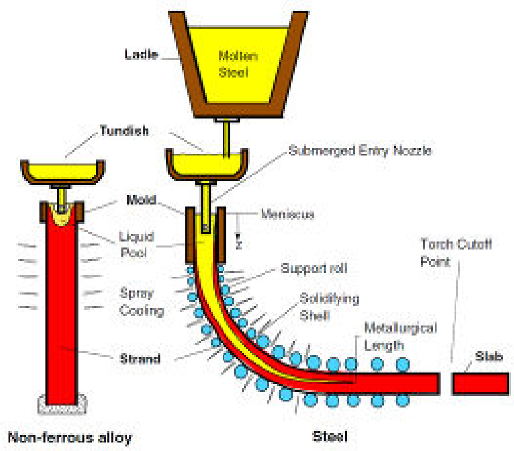

Fig.1.a Vertical continuous casting machine

Vertical continuous casting machine characteristics studied are:

Melting pot - 100 tons of molten alloy steel;

Number of threads -3;

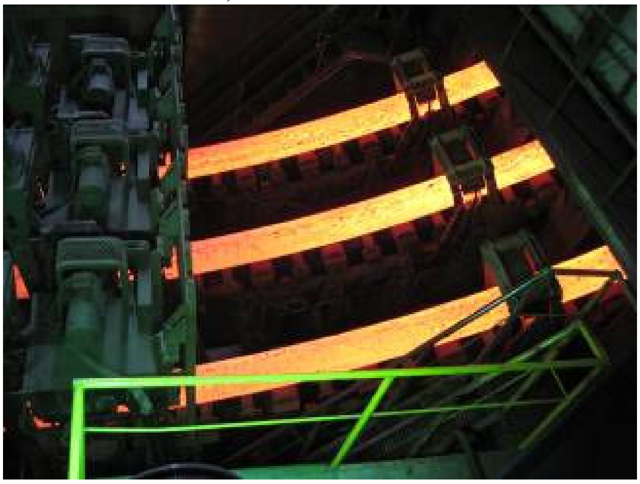

Fig.1.b Vertical continuous casting machine- three wires

Radius wire- 13, 000 mm;
Tundish capacity - 17 tons;
Crystallizer-mold vertical design of Cu-Cr-Zn;
Jet protection between distributor and mold- immersed tube;
Max-speed casting- 5m/min;
Secondary cooling- water jets.

The plant is designed for continuous casting of round billets with a diameter of 350 mm and maximum size 400x250 mm slabs [4]. Cylinders of withdrawal, the upper and lower stands and withdrawing schedule are shown in fig. 2 and fig. 3.

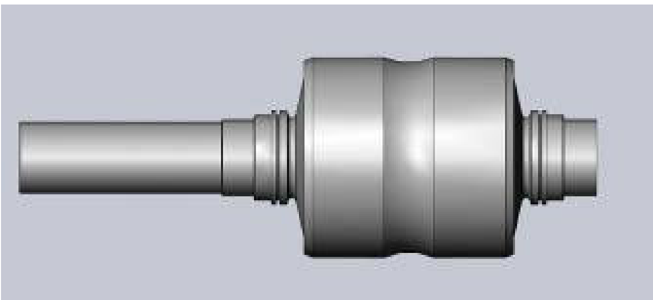

Fig.2 Upper cylinder at continuous casting machine

Fig.3 Lower cylinder at continuous casting machine

In fig. 4 is presented the drawing stands, straightening providing semi-withdrawal. In this installation of continuous casting ingot size change is necessary to change the withdrawal cylinders which are processed according to each profile dimension withdrawn. This change is necessary only for round profiles, each cylinder of different radius withdrawal being processed [5], [6]. This is detailed in fig.4.

Continuous casting machine described above is used to obtain the round profile with the following diameters: Ø100mm, Ø250mm, Ø280mm and Ø350mm. When changing the size and profile is needed to replacing retired withdrawal cylinders for each size separately. This has several disadvantages:

-Long times (~ six hours) required to change the twenty-four metal cylinder with an average weight of 450 kg each;

-Change cylinders, requires adjustments and calibrations after their installation in stands of withdrawal;

-Large space for storage and transfer of cylinders.

To remove this disadvantage, the authors propose the design and optimization of a pair of rollers capable of withdrawing multiple ray withdraw all four sizes of round profiles.

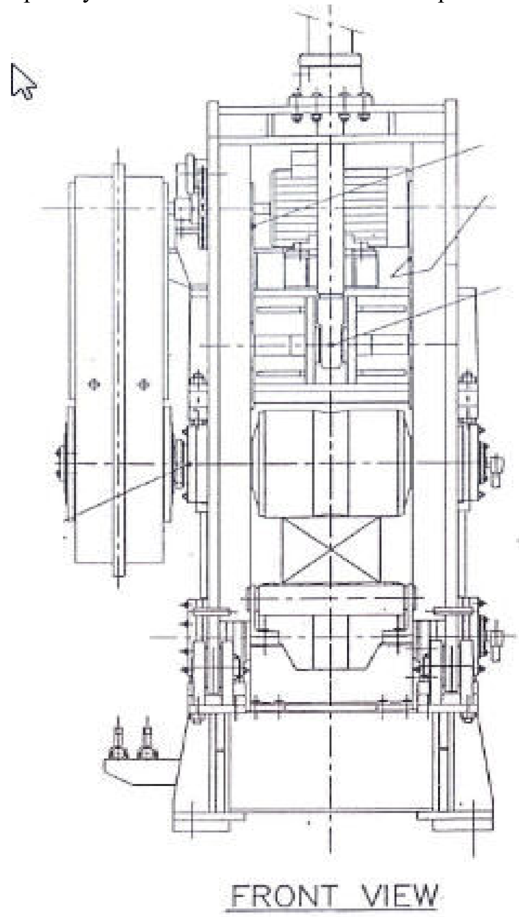

Fig.4 Stand for withdrawing cylinders at continuous casting machine of steel

B. *Modeling and simulations of cylinders*

The design and optimization was performed using optimization techniques and CAD (Computer Aided Design) and CAE (Computer Aided Engineering) design and simulation using finite element method for the cylinder designed. Our was aimed to achieve a cylinder which will be used to withdraw the four dimensions of semi- finished round with diameters of Ø180mm, Ø250mm, Ø280mm and Ø350mm. At first experimental measurements were made in continuous casting process to determine the features of withdrawal of profiles. The main parameters that influence the process of withdrawal, namely:

-The pressure applied to upper cylinder [bar]

-Casting temperature (done over temperature liquids) [°C]

-Withdrawal speed [m / min]

-Profile diameter [mm]

Results of experimental determinations, statistically, show the interdependence of these parameters, one depending on the other three.

Parts of the quantities measured are presented in Table 1.

TABLE I
QUANTITIES MEASURED AT WITHDRAWAL INSTALLATION

Diameter [mm]	Pressure [Barr]	TLiq [°C]	ΔT [°C]	S_{wd} [m/min]
180	63	1523	44	1.85
180	62	1522	33	1.95
180	62	1523	34	2.00
180	62	1522	36	1.90
180	62	1523	42	1.80
180	60	1522	43	1.75
180	63	1522	10	2.45
180	63	1520	43	1.75
180	63	1520	22	2.20
180	63	1523	31	2.00
180	63	1523	37	1.80
180	63	1506	33	1.80
180	63	1506	14	2.20
180	62	1508	21	1.90
250	68	1495	31	0,82
250	68	1495	25	0,88
250	68	1495	23	0,92
250	68	1494	30	0,9
250	68	1494	30	0,9
250	68	1494	35	0,85
250	68	1494	33	0,88
250	68	1494	28	0,9
250	68	1494	18	0,9
250	68	1494	14	0,85
250	68	1494	13	0,85
250	68	1494	12	0,88
250	68	1494	10	0,88
250	70	1494	38	0,8
250	70	1494	37	0,8
350	77	1498	35	0.45
350	77	1498	36	0.50
350	77	1498	25	0.50
350	77	1498	28	0.55
350	77	1498	28	0.55
350	76	1499	21	0.55
350	75	1499	24	0.55
350	75	1499	19	0.60
350	75	1499	18	0.60
350	76	1497	26	0.55
350	76	1497	29	0.55
350	76	1497	23	0.55
350	76	1497	24	0.55
350	76	1498	31	0.50
350	76	1498	34	0.50

After statistical processing were obtained the following results:

The statistical analysis shows the following:

-applied to higher-pressure cylinder is directly proportional to the diameter of the ingot withdrawn;

-withdrawal rate increases when Δt over liquidus temperature decreases;

-speed of withdrawal is closely correlated and dependent on the size of the blank and higher cylinder pressure to withdraw (fig. 5, 6, 7, 8, 9, and 10).

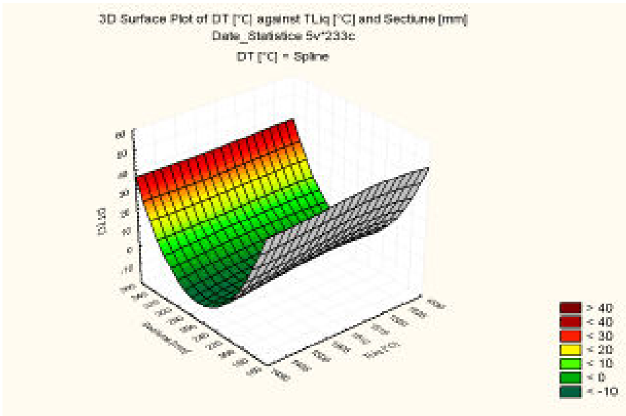

Fig.5 3D Surface Plot of DT [°C] against TLiq [°C] and Section [mm]

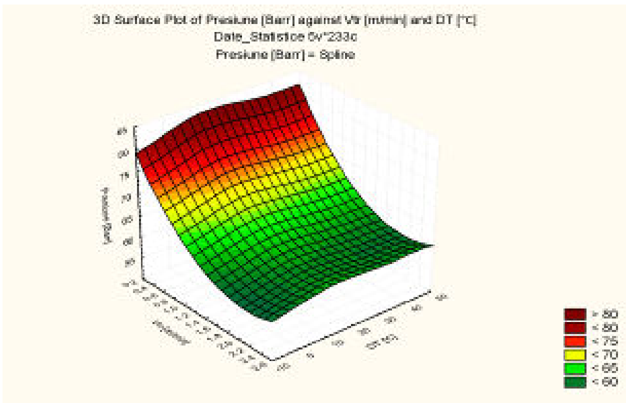

Fig.6 3D Surface Plot of Pressure [Barr] against Str [m/min] and ΔT [°C]

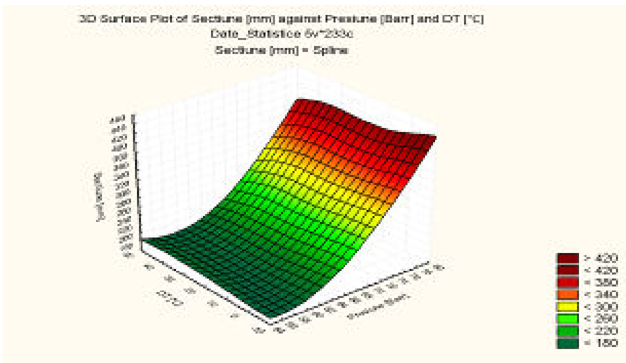

Fig.7 3D Surface Plot of Section [mm] against Pressure [Barr] and ΔT [°C]

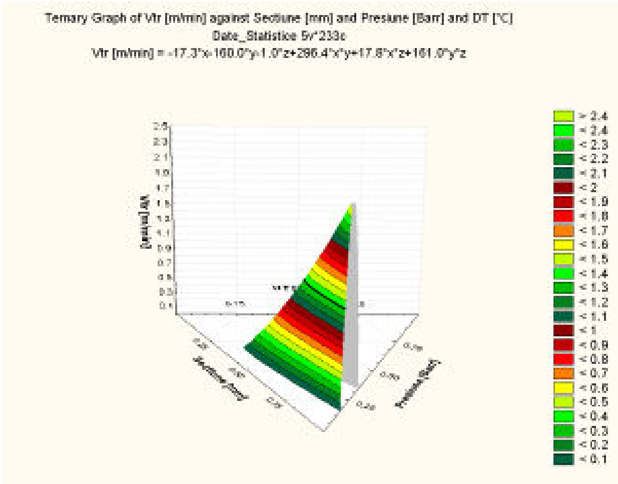

Fig.8 Ternary Graph of Str [m/min] against Section [mm] and Pressure [Barr] and ΔT [°C]

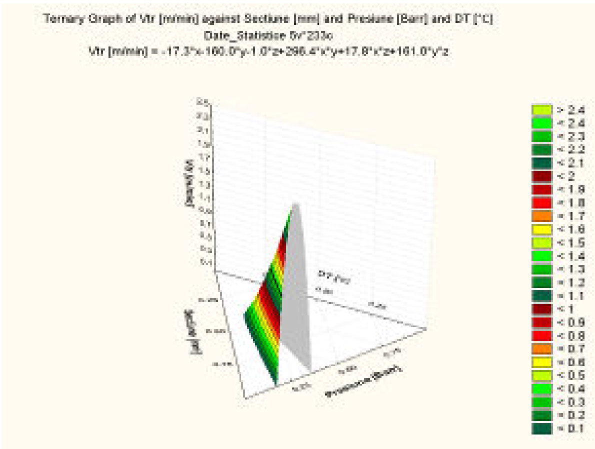

Fig.9 Ternary Graph of Str [m/min] against Section [mm] and Pressure [Barr] and ΔT [°C]

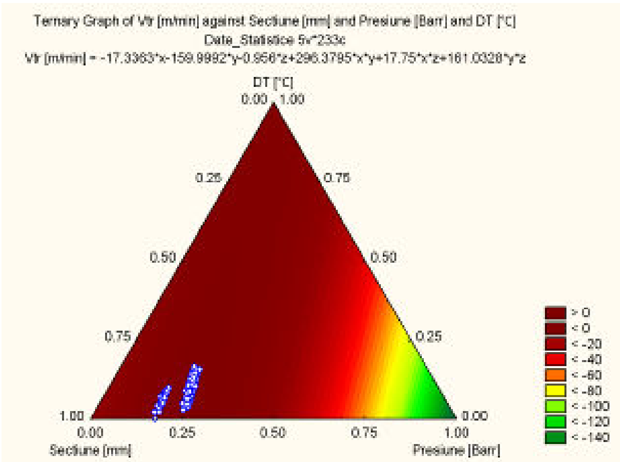

Fig.10 Ternary Graph of Str [m/min] against Section [mm] and Pressure [Barr] and ΔT [°C]

Solids body and drawing of withdrawing projects new cylinders with multiple radiuses are identified in fig. 11, 12, 13 and 14.a. , 14.b. and 14.c

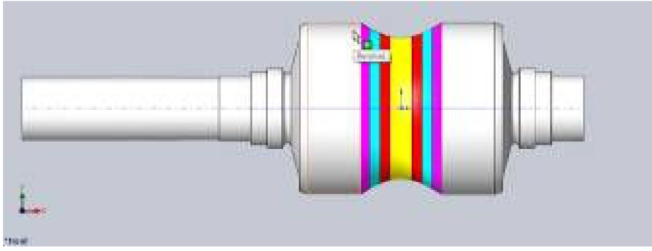

Fig.11 Upper cylinder with multiple radiuses

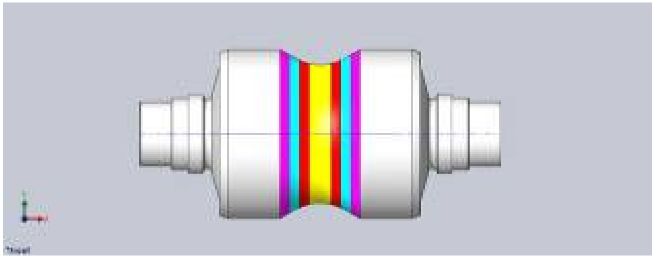

Fig.12 Lower cylinder with multiple radiuses

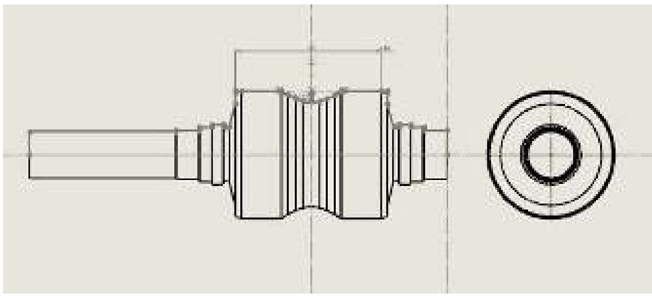

Fig.13 Drawing for upper cylinder with multiple radiuses

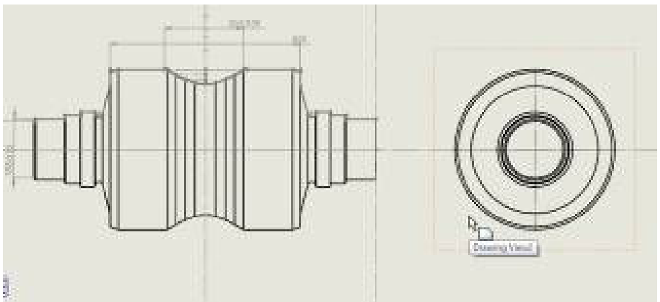

Fig.14.a Drawing for lower cylinder with multiple radiuses

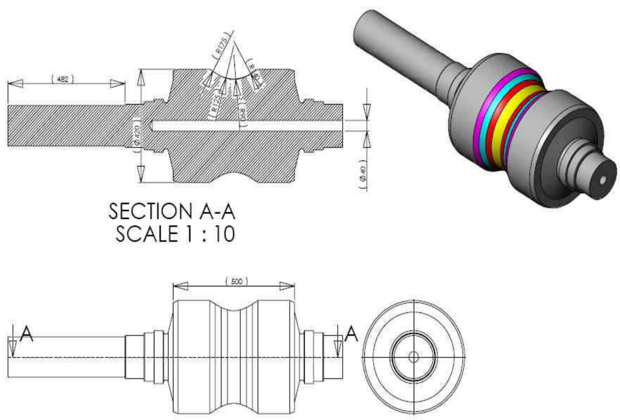

Fig.14.b Drawing and section for upper cylinder

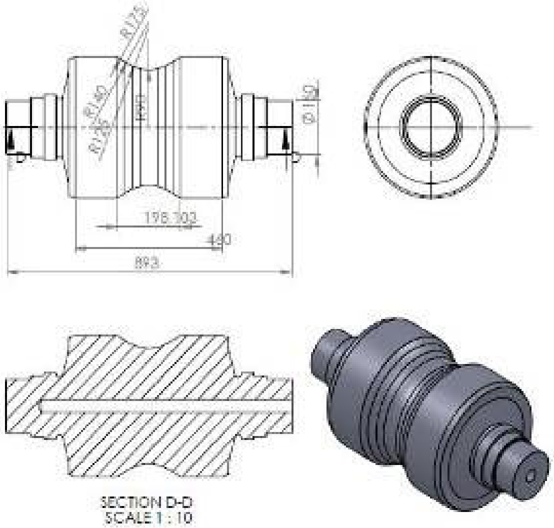

Fig.14.c Drawing and section for lower cylinder

III. Results of simulations

After the simulations performed by FEM (Finite Element Method), it is found that the ideal diameter machined on the cylinder, which is identical to that of blank shot, because it provides maximum surface contact, between roller and blank. This gives a maximum tightening force on the semi-cylinder, good heat and exhaust to avoid strains on the blank. In fig.15 it shows the cylinder withdrawal processed with multiple beams, which may withdraw four types of performs without changing cylinders. The solid model for nonlinear dynamic study with finite element is presented in fig. 15.

The above fig. 16, 17, 18 show the results of static simulation, which was realized at four cylinders with four radiuses, and the results of stress, strain and displacement.

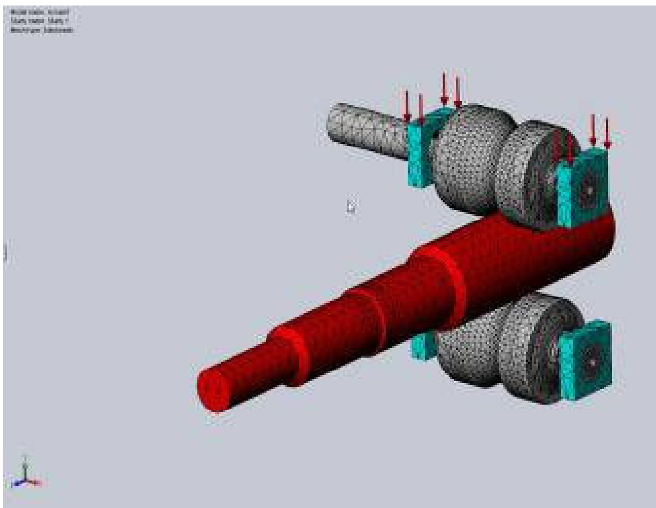

Fig.15 Solid model and mesh for study

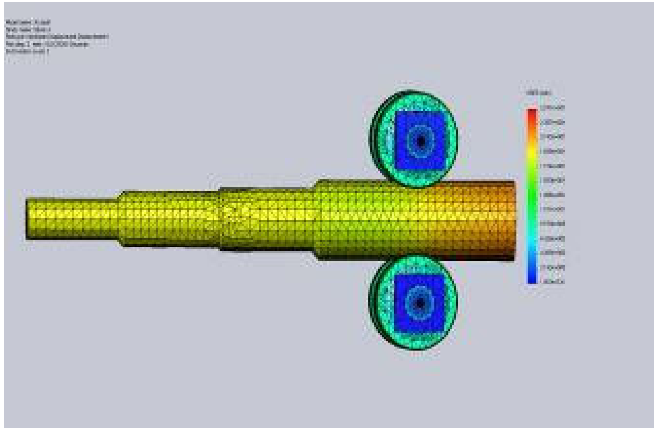

Fig.16 Result for displacement

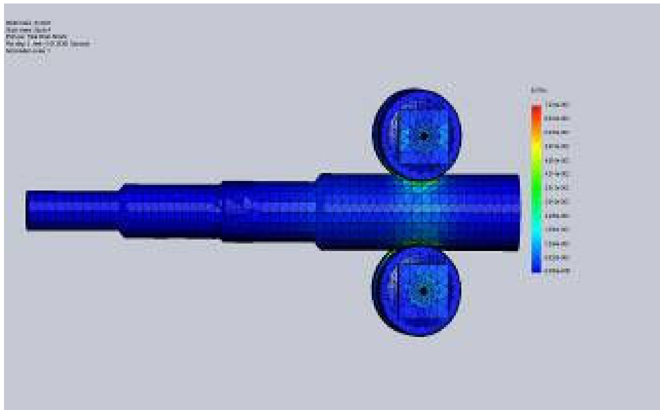

Fig.17 Result for strain

It is found that by applying the same loads as in the case of cylinders with a single radius the critical values are not exceeded.

This shows that the authors proposed solution is viable and can be applied in the withdrawal of the semi-finished at vertical continuous casting of steel with curvilinear wire.

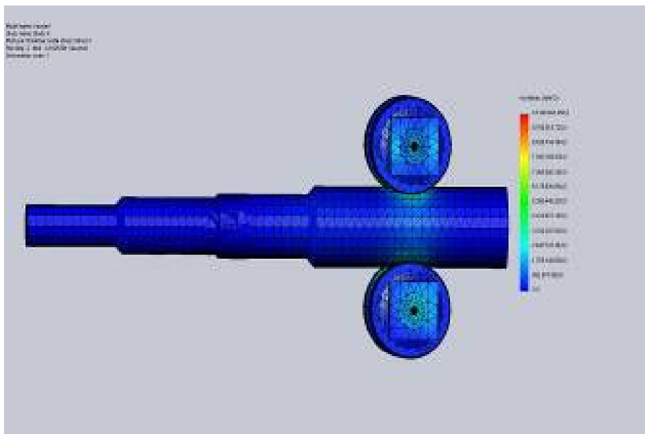

Fig.18 Results for stress (Von Mises)

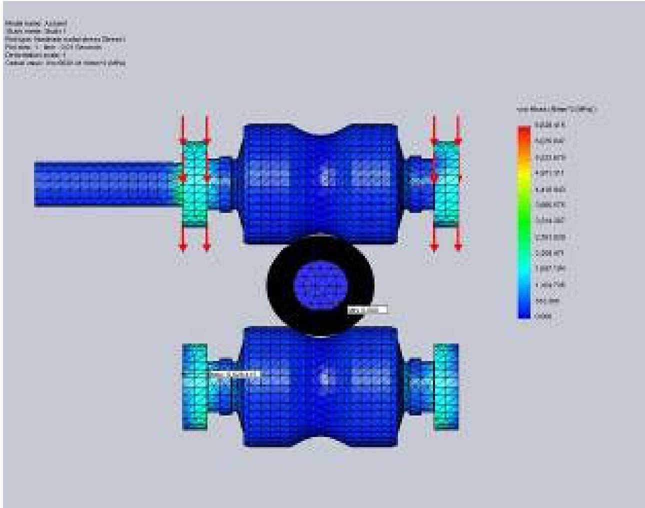

Fig.19 Results for stress at semi-finished with Ø350mm

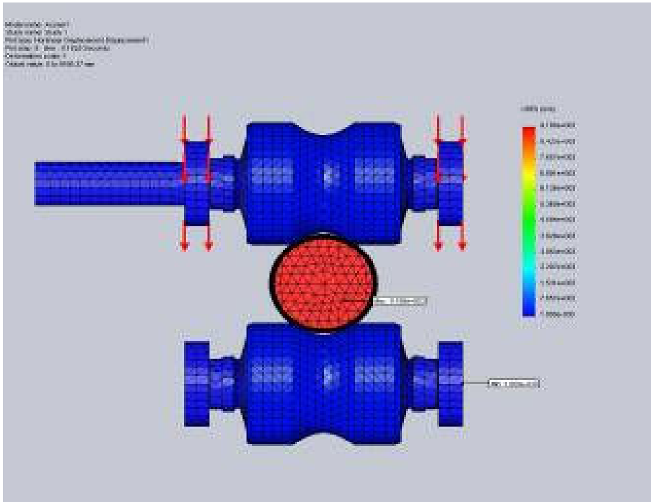

Fig.20 Results for displacement at semi-finished with Ø350mm

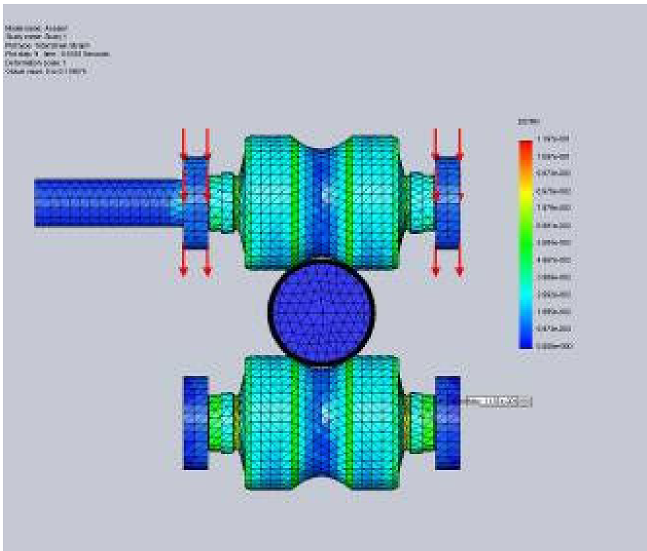

Fig.21 Results for strain at semi-finished with Ø350mm

In fig. 19, 20, 21 are presented results for stress, strain and displacement at the simulation in case of withdrawal of a semi-manufactured Ø 350 mm diameter. Note that the values do not exceed permissible values for the parameters studied and there are no major deformations of semi-finished [7], [8], [9]. Simulations carried out for semi-manufactured with diameters of Ø180 mm, Ø250 mm and Ø280 mm led to similar results commensurate with the diameter of semi-finished profile withdrew [10], [11], [12], [13], [14].

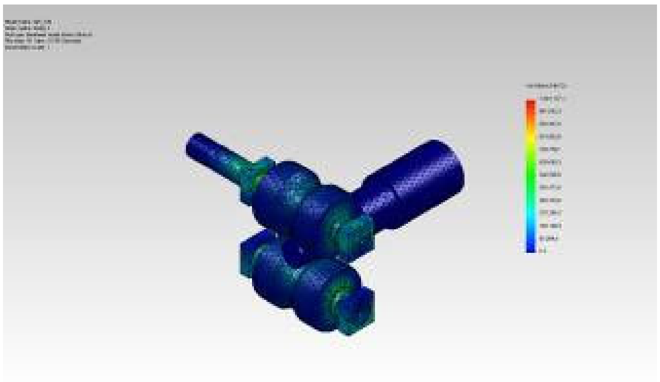

Fig.22 Results for stress at FEM simulation for Ø1800mm diameter

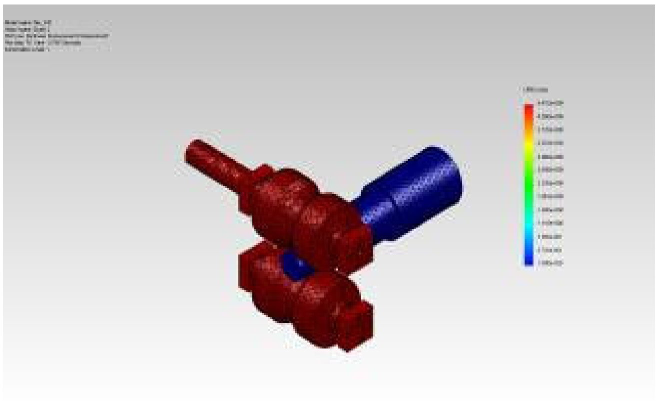

Fig.23 Results for displacement at FEM simulation for Ø180mm diameter

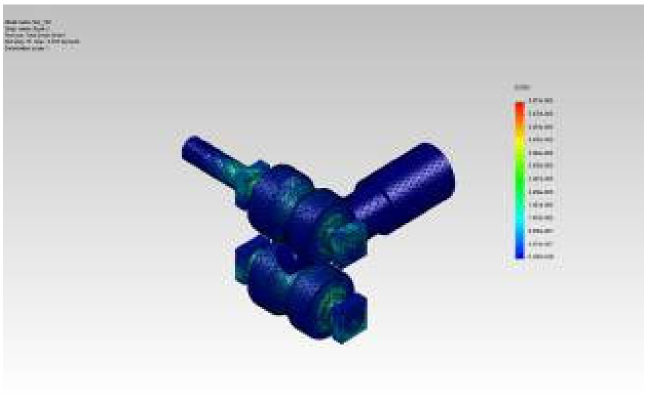

Fig.24 Results for strain at FEM simulation for Ø180mm diameter

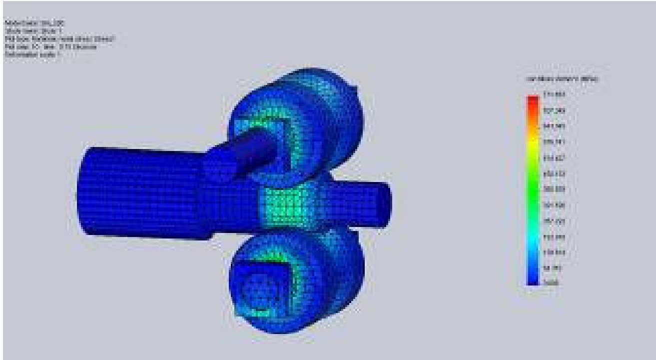

Fig.25 Results for stress at FEM simulation for Ø250mm diameter

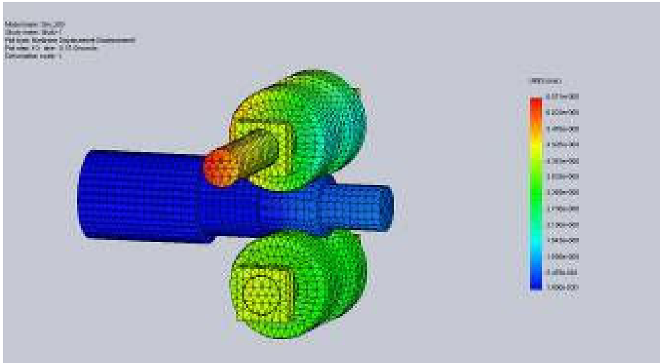

Fig.26 Results for displacement at FEM simulation for Ø250mm diameter

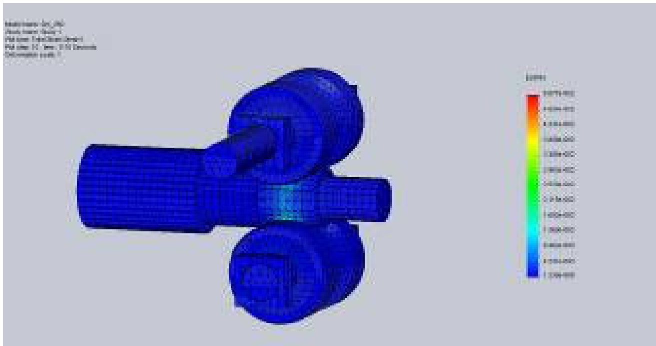

Fig.27 Results for strain at FEM simulation for Ø250mm diameter

In Figures 22-33 shows the results of nonlinear dynamic simulation carried out on the semi-finished with diameters: Ø150mm, Ø250mm, Ø280mm, Ø350mm.

Load on cylinder to withdraw was established according to the measurements of Chapter 2 (see Table I). The purpose of simulation is to determine if they exceeded the limit values of stress and strain to withdraw with multiple cylinder radiuses. From the data gathered through simulations (see Table II) pointed out that the permissible values are not exceeded, which validates theoretical the method proposed by the authors.

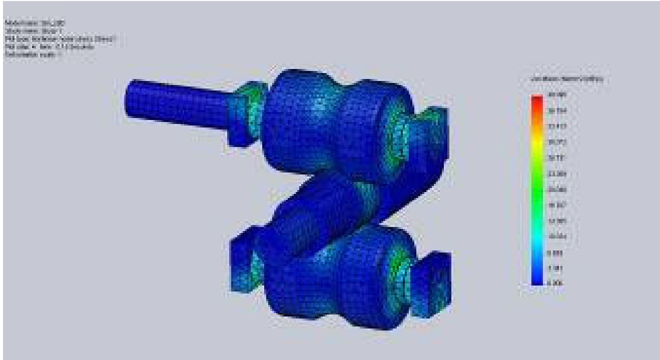

Fig.28 Results for stress at FEM simulation for Ø280mm diameter

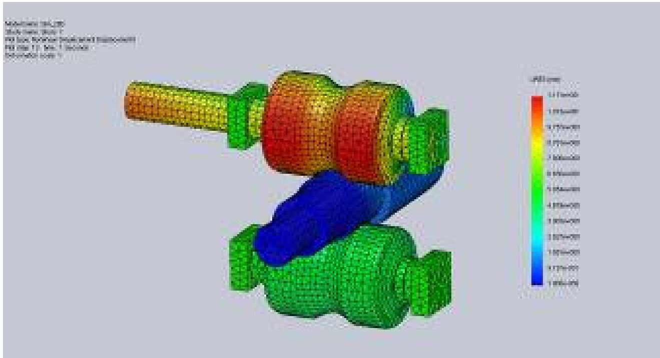

Fig.29 Results for displacement at FEM simulation for Ø280mm diameter

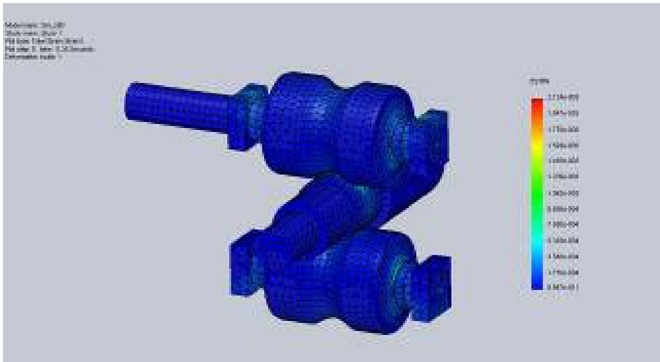

Fig.30 Results for strain at FEM simulation for Ø280mm diameter

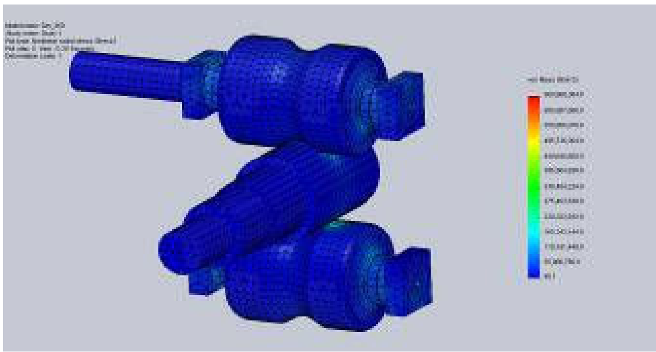

Fig.31 Results for stress at FEM simulation for Ø350mm diameter

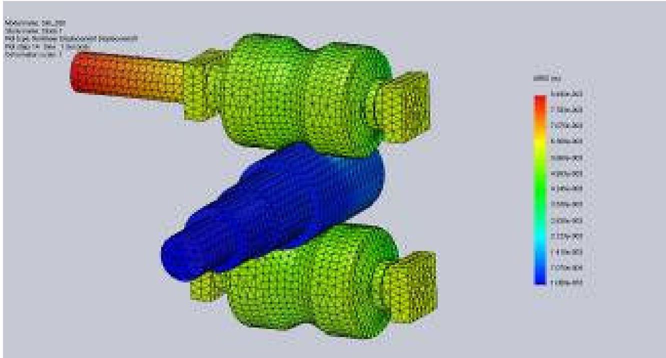

Fig.32 Results for displacement at FEM simulation for Ø350mm diameter

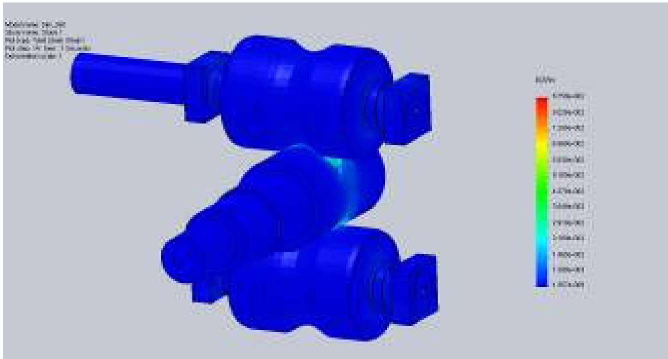

Fig.33 Results for strain at FEM simulation for Ø350mm diameter

TABLE II
RESULTS FOR STRESS, DISPLACEMENT AND STRAIN AT SIMULATIONS

SIZE	NAME	TYPE	MIN	MAX
Ø 180 MM	Stress1	VON: von Mises Stress at Step No: 76(0.745 Seconds)	0 N/m^2 Node: 1	1.08114e+006 N/m^2 Node: 4270
	Displacement1	URES: Resultant Displacement at Step No: 76(0.745 Seconds)	0 mm Node: 1	4.47024 mm Node: 2872
	Strain1	ESTRN: Equivalent Strain at Step No: 76(0.745 Seconds)	0 Element: 1	5.97364e-006 Element: 29267
Ø 250 MM	Stress1	VON: von Mises Stress at Step No: 10(0.75Sec)	0.0058472 N/mm^2 (MPa) Node: 8883	(-719.044 mm, -76.6945 mm, 75.4134 mm)
	Displacement1	URES: Resultant Displacement at Step No: 10(0.75Sec)	0 mm Node: 464	(-87.5 mm, -202.715 mm, -875 mm)
	Strain1	ESTRN: Equivalent Strain at Step No: 10(0.75Sec)	1.33878e-008 Element: 52582	(-736.068 mm, -73.0081 mm, 61.7577 mm)
Ø 280 MM	Stress1	VON: von Mises Stress at Step No: 4(0.15Sec)	0.000142274 N/mm^2 (MPa) Node: 8924	(-779.371 mm, -56.9791 mm, 75.3134 mm)
	Displacement1	URES: Resultant Displacement at Step No: 13(1Sec)	0 mm Node: 1	(45 mm, -276.328 mm, 625 mm)
	Strain1	ESTRN: Equivalent Strain at Step No: 5(0.25Sec)	8.84689e-011 Element: 55394	(-917.044 mm, 23.8026 mm, 27.2452 mm)
Ø 350 MM	Stress1	VON: von Mises Stress at Step No: 5(0.25Sec)	65.1251 N/m^2 Node: 10592	(-869.721 mm, -33.3816 mm, -70.2343 mm)
	Displacement1	URES: Resultant Displacement at Step No: 14(1Sec)	0 m Node: 1	(45 mm, -276.328 mm, 1000 mm)
	Strain1	ESTRN: Equivalent Strain at Step No: 14(1Sec)	1.35685e-009 Element: 43603	(-890.202 mm, 20.1313 mm, 63.1389 mm)

IV. CONCLUSION/ FURTHER WORKS

Following the analysis made by the authors on the process of withdrawal of the vertical continuous casting with curvilinear wire, it is found that the method of withdrawal cylinders with a single radius shows disadvantages. Given the importance of continuous casting of metals in the steel and metallurgical general flow, is required to modernize and optimize existing continuous casting plant to increase product quality and reduce energy consumption. Withdrawing method with multiple radius cylinders of the semi-manufactured proposed by authors, will be practic realised on a smaller scale to validate the principle and then to be implemented in the profile industry. Shall have regard to future research on the achievement of modernization and improvements to existing facilities and the development of new mechanical systems for withdrawing horizontal continuous casting and improve vertical continuous casting instalations.

A pair of cylinders with a single radius profile allows removal of a single round sizes, of the semi-finished and has disadvantages:

-Is necessary to change all four cylinders at retirement for each profile dimension stands

-Continuous casting machine productivity loss due to downtime;

-Needed to change cylinders;

-Dead-time due to need adjustment after changing cylinders;

-Large space required for storage of cylinder.

By using multiple beams cylinders authors proposed withdrawing all of the above disadvantages can be removed.

This implementation in semi-finished withdrawal process in continuous casting machines, multiple cylinder radiuses contributes to:

1. Increase productivity-continuous casting of steel,

2. Reducing downtime required to change cylinders withdrawal

3. Material and labor-saving, necessary to build a set of cylinders for each dimension of semi-manufactured;

4. The possible withdrawal of blooms with multiple cylinder radius withdrawal.

Future research will focus on the practical withdrawal of these cylinders and testing them on a continuous steel casting plant to validate the method proposed by the authors.

Processing will be carried out using cylinders CAM (Computer Aided Manufacturing), precision processing is required to ensure proper functioning of the cylinders of withdrawal for semi-finished of steel..

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