UDC 621.771.06 :669.1/.2

Experimental Twin-Roll Casting Equipment for Production of Thin Strips

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The features of construction and main technical characteristics of the self designed experimental twin-roll caster for production of strips with 1…5 mm thickness and 200 mm width of non-ferrous metals and steels are described. An analysis of scientific literature about construction of existing laboratory devices for alike application is carried out. On that basis, conclusions about advantages and potentials of suggested technique are made.

Keywords: TWIN-ROLL CASTING, EXPERIMENTAL DEVICE, THIN STRIPS, NON-FERROUS METALS, STEEL

Introduction

One of most priority areas of Ukrainian metallurgy development, that enable to keep competitiveness of domestic plants in the world market under conditions of conventional gas and electric power prices rise, is implementation of advanced power saving technologies. Reduction of number of hot processing operations has become a traditional method to decrease resource consumption in iron and nonferrous industry since the second half of 20th century. Decreased cross-section of initial cast was necessary which led to creation of cast-rolling plants (CRP) for production of sheets and rolled section [1, 2]. In such plants continuous casting machine (CCM) operates synchronously and in the production line with one or several hot rolling stands. Current sheet CRP are equipped with thin slab casting machines with oscillating molds enabling to produce hot-rolled flat section 0.8-12.7 mm thick from a cast 50-90 mm thick [3]. To maintain relatively high reduction, in most cases continuous groups of such plants consist of 6 or 7 four-high stands. Besides, through-type furnace 158-261 m long is necessary for decrease of temperature gradient on the cross-section of thin slab after CCM [3].

Energy consumption reduction due to absence of intermediate heating and decrease of number of hot rolling stands to 3 at similar range of products is possible when CCM with moving crystallizer is applied. Thickness of cast produced on this CCM is 10-20 mm for one-line and 12-70 mm for two-line machines [4]. Such CRP are widespread in production of light metal alloy sheets. Technical University of Clausthal in collaboration with company Salzgitter AG (Germany) have been working on development of this technology for the production of flat section from perspective microalloyed steel grades during the last decade [5]. Industrial start-up of pilot plant is planned in 2012.

CRP with mobile roller crystallizer is even more high-potential in view of economic parameters. From them twin-roll casters are the most widespread [6]. Such industrial CRP are very compact and flexible, include only one hot rolling stand (**Figure 1**) and produce sheets 0.5–5.5 mm thick. The range of cast strip sizes at the exit from twin-roll crystallizer is between 1.5 and 9.5 mm. After solidification in water-cooled rolls, metal can be subjected to large deformation that improves surface quality, microstructure and properties of metal [2].

Sheet production on CRP with twin roll-casters has already become well-established when producing sheets from aluminum and its alloys. Now more than 200 such plants operate in the world. Italian company Fata-Hunter and Canadian company Novelis are admitted leaders in the area of manufacture of CRP equipment for light metals and alloys. For today two twin-roll casters SuperCaster Plus ® produced by FATA Hunter (without hot rolling stands) operate in Ukraine at

JSC "Zaporizhzhya Aluminum Integrated Works" and produce sheets from primary pure aluminum. It is necessary to note, however, that application of twin roll-casting method when producing steel flat section has only several examples of industrial implementation in the world. Insufficient experimental base for conduction of investigations and limited information about results of carried out investigations in the foreign scientific and technical literature are one of the factors that prevent a wide spread of this technology in the world steel-rolling practice. The latter is related to that research centers associated with the large industrial companies estimate the key constructive and technological solutions as know-how elements. Nevertheless, in this paper authors will consider the known experimental twin roll-casters, analyze their features and differences from each other. Current industrial plants with twin-roll crystallizers are reviewed in works [2, 6].

Results and Discussion

Current experimental twin-roll casting equipment

Analysis of publications devoted to investigations of twin roll-casting process enables to conclude that the most of them are carried out in five world-famous scientific centers: Rheinisch-Westfalische Technische Hochschule, Aachen, Max-Planck Institut für Eisenforschung, Düsseldorf (Germany), Oxford University (Great Britain), Institute of Technology, Osaka (Japan) and Institute of Industrial Materials, Bouchervill (Canada).

Native scientists were also investigating the issues of thin sheet production directly from the melt. So, strip production techniques in roller crystallizers for inoculated cast-iron, fool steels, hard alloys and solders [8] were successfully completed in Odessa Research Institute of Special Casting Methods by the end of 1970s. Corresponding equipment was developed for investigations and subsequent industrial implementation. The distinctive feature of this equipment was the impossible metal flow between thin-walled water cooled rollers. Therefore, this method cannot be referred to twin roll-casting for which reduction of material after solidification directly between roll-crystallizers is characteristic.

Pilot plant of Institute of Metal Forming in Aachen developed in cooperation with company Thyssen Krupp Stahl AG (**Figure 2**) is the most advanced of experimental CRP with twin roll-caster in respect of equipment possibilities [9]. The distinctive feature of this plant is through passing of metal through a mobile crystallizer, hot rolling stand and two cooling sections enabling to have conditions of laboratory experiments close to industrial ones as well as to carry out thermo-mechanical treatment of material with controllable change of temperature and optimum structure and properties of sheet. CRP in other research centers consist of only modules with roller crystallizers. The principal characteristics of experimental cast-rolling modules are compared in **Table 1**.

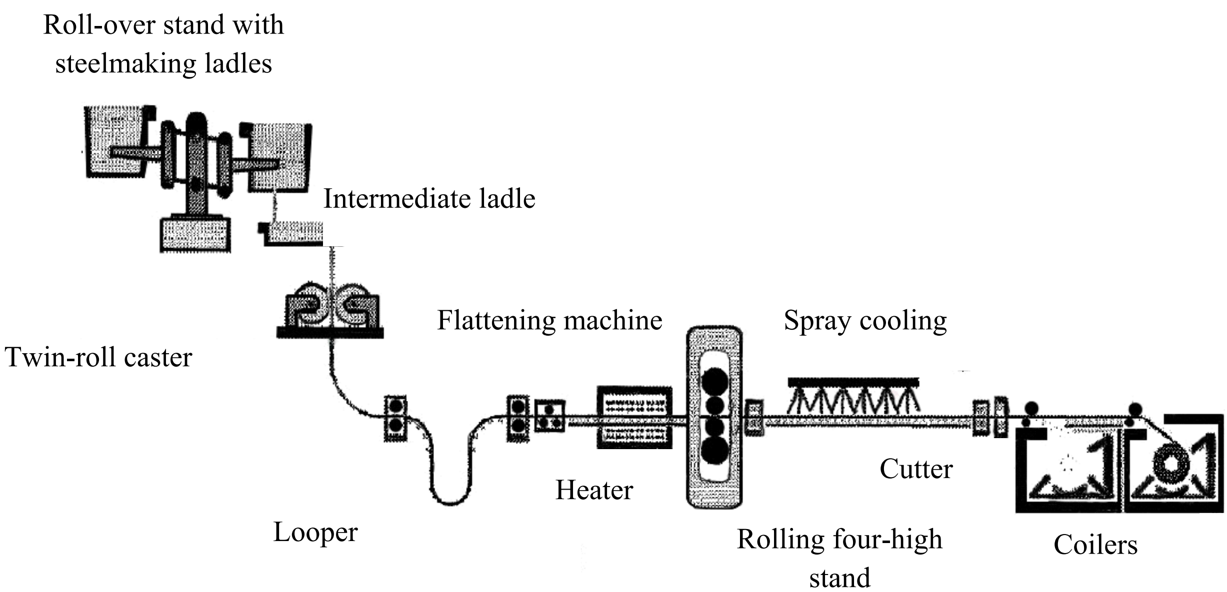

Figure 1. Composition and lay-out of industrial CRP with twin-roll caster on the example of line for steel sheet production at ThyssonKrupp Stahl AG, Krefeld (Germany) [7]

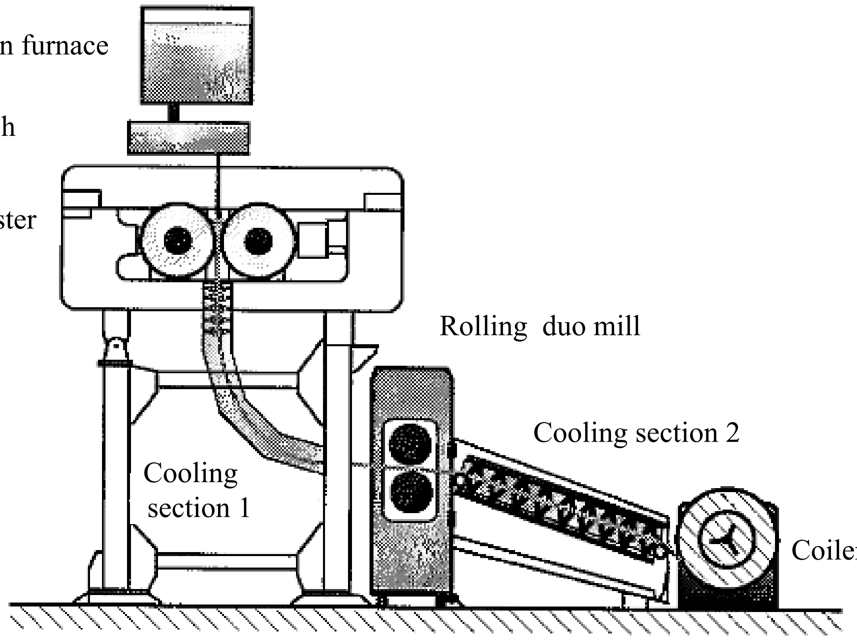

Figure 2. Pilot twin-roll caster for strip production developed by Institute of Metal Forming of Rheinisch-Westfalische Technische, Aachen

Table 1. Principal characteristics of current experimental twin-roll casters

Research center	Casting direction	Roll diameter, mm	Shell material	Width of roll work area, mm	Maximum casting rate, m/min	Thickness of cast strip, mm	Maximum mass of melt, kg	Casting material
Rheinisch-Westfalische Technische, Aachen	vertical	580	Cu-Cr-Zr, Ni-plated	150	60	0.6-3	180	steel
Max-Planck Institut für Eisenforschung, Düsseldorf	vertical	330	Elbrodur NIB CH48	120	51.8	1-20	70	steel
Oxford University, Oxford	horizontal vertical	400 600	die steel	250	60	0.5-6.5	60	Al-alloys
Institute of Technology, Osaka	vertical	1500	Cu	100	60	3	n/a	Al- alloys 6xxx series
	vertical	250-300	Cu	50…100	180	1-2.6		Al- alloys
	horizontal	300	Cu	100	60	1.8-3.2		Al- alloys
Institute of Industrial Materials, Bouchervill	vertical	600	Cu-alloy	200	12	4-7.5	1000	Steel and nonferrous metals

Analysis of data in **Table 1** shows that vertical casting process is preferable at designing experimental twin-roll casters (**Figure 2**) when liquid metal is supplied in interroll space and moves from the furnace to tundish and further on feeder channels to crystallization-deformation zone under action of gravity. Such configuration of cast-rolling module is more multiple-purpose. This priority is difficult to realize under industrial conditions but it is a considerable advantage for research equipment. It is necessary to note that commercial twin-roll casting equipment for production of aluminum and magnesium alloy sheets are usually manufactured with horizontal design.

Roll-crystallizers of CRP are water cooled. The key constructive elements of the roll are: axis bearing mechanical loading during the process;

shell is in direct contact with molten metal and provides intensive heat-removal from crystallization-deformation zone; channels for circulation of cooling liquid. The example of roll design of twin-roll caster is illustrated in **Figure 3** [10]. Use of roll with many channels located along the working surface of the shell is explained by the purpose to give a crystallizer more stiffness. At the same time, the total mechanical compliance of twin-roll caster mills is much higher than in sheet mills. So, the longitudinal uneven gauge can reach 0.9 mm [11]. And the change of deformation force over the time has an oscillating pattern, for one of the reasons according to authors is the unevenness of the shell temperature field due to different distances of its external surface points from cooling channels. This effect has additional disturbing effect on stability of pouring process that finally leads to strip deterioration.

It is accepted that increase of roll-crystallizer diameter enables to expand sheet assortment produced on CRP towards higher thicknesses and also provides an increase in plant efficiency [6]. At the same time, analysis of **Table 1** shows that the thickest strips were produced on the plant of Max-Planck Institut für Eisenforschung. Maximum teeming rates of 180 m/min were reached in Institute of Technology of Osaka on twin-roll caster with roll diameter 300 mm thus that this scientific center has the casting-rolling module with outer size of shell 1500 mm. It is also necessary to take into consideration that increase of roll diameter leads to increase of weight and, as consequence, rise in equipment cost. The width of shell working section in the experimental twin-roll caster is chosen depending on drive power.

The most of experimental twin-roll casting modules have a maximum rate of more than 50 m/min. In addition, analysis of data introduced in **Table 1** shows that the most investigations are carried out at casting rate 10 times smaller than its limits specified in equipment`s characteristics. On the other hand, rather low deforming ability limited by peak torque of the motor is a weak point of current experimental plants. So specific forces of deformation of shell working area in the range from 0.13 to 0.67 kN/mm are characteristic for twin-roll casting of steel [7, 11]. Further force enhancement is dangerous and automatic control system responds by increase of roll gauge [11]. The maximum specific force on the tool when producing aluminum strips from the melt is 0.1 kN/mm according to T. Haga and S. Suzuki. It is obvious that possibilities of carrying out research to estimate the influence of plastic forming in crystallization-deformation zone on surface quality, structure and properties of strips on present plants are restricted.

Thus, based on analysis of design features of known experimental twin-roll casting equipment it is possible to draw a conclusion on the necessity of working out new similar-purpose laboratory machine with the following properties: all internal surface of shell has contact with cooling liquid; roll diameter is from 300 to 400 mm; width of working area of crystallizer is between 50 and 250 mm; equipment is capable to provide high metal flow directly after crystallization.

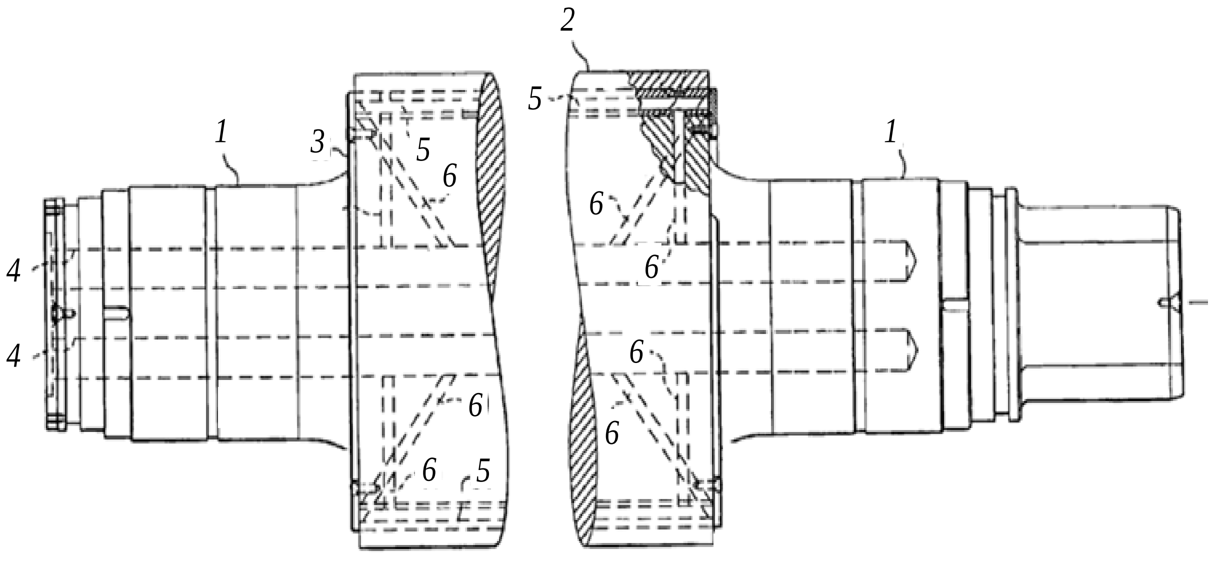

Figure 3. Design of CRP roll-crystallizer: *1* - roll line, *2* - shell, *3* – side pressure sealing plate, *4* - cylindrical channels for water, *5* - cylindrical channels of shell cooling, *6* - radial channels [10]

Original experimental twin-roll caster for production of thin strips

In 2008, experimental twin-roll caster comply specified with the requirements was designed as part of scientific cooperation of Metal Forming Department (National Metallurgical Academy of Ukraine) with Institute of Materials Science of Leibniz Universitaet Hannover (Germany). Manufacture of machine details including more than hundred original knots and elements took more than one and a half years. Machine assemblage was started in the end of 2009 in laboratory of Institute of Materials Science. First trial casting was commissioning and realized on March 19, 2010. The layout of the designed experimental twin-roll caster is shown in **Figure 4**.

The rolls are driven by an ac motor with the maximum power 4.4 kW and speed 1500 rpm. The next element of the main line of cast-rolling plant is a reducing gear with reduction ratio 220. Stand is connected to shaft end portions by drive shaft means of cardan shafts that are able to change their length from 850 to 950 mm and transfer torque at angles of azimuth to 14°. Such characteristics of coupling apparatus allow changing stand installation angle from 0° (vertical scheme of molten material supply corresponding to actual position of equipment (**Figure 4**)) to 90°.

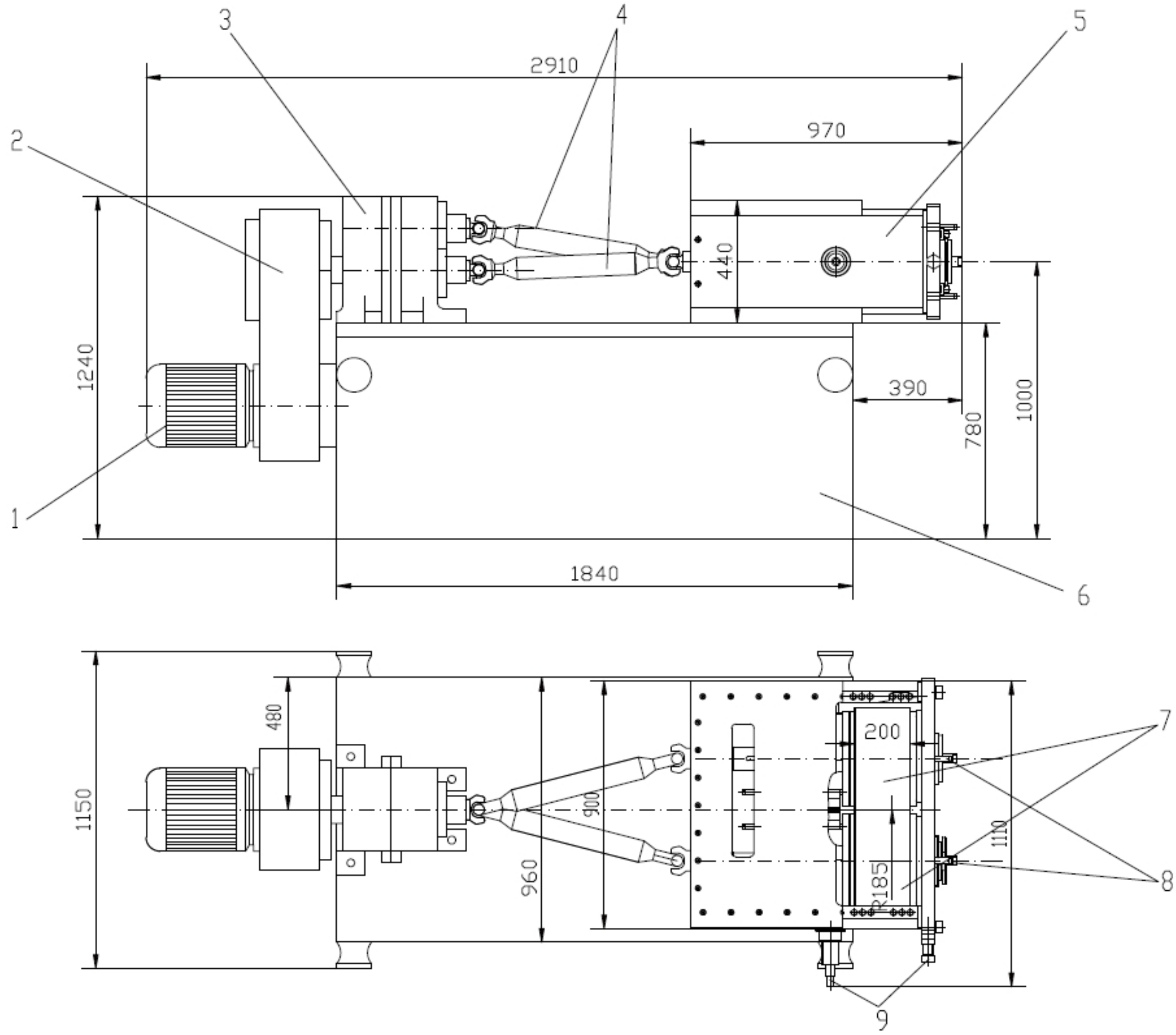

Figure 4. The main line of designed experimental twin-roll caster: *1* - ac motor, *2* - reduction gear, *3* - drive shaft stand, *4* - cardan shafts, *5* –twin-roll casting mill, *6* - frame, *7* - roll-crystallizers, *8* - cooling liquid connection, *9* - jack screws

The possibility to change casting direction makes this experimental plant with twin-roll crystallizer all-purpose and is its distinctive property, not featured by other laboratory machines. One more feature of designed cast-rolling module stand is two jack screws with individual adjustment of their position. It enables to produce cast strips with target cross-section wedging and also will facilitate study of structure formation and properties of material under conditions of pre-defined non-uniform plastic deformation across the width of crystallized sheet.

Rolls of experimental twin-roll casting equipment are segmented. Water with constant temperature of 16 °C circulating on the close-cycle of cooling system completely flushes internal surface of shell. The tool is made of hotworking steel X38CrMoV5-3 (1.2367) and subjected to heat treatment: austenitization, air hardening and tempering. Hardness of material surface was 40 HRC as a result of heat treatment. In the future it is planned to apply copper-based alloy shells with additives of chromium and zirconium having higher values of heat conductivity and mechanical properties. The key technical characteristics of the designed twin-roll caster are shown in **Table 2**. Determination of values of the specified parameters was carried out taking into account results of mathematical modeling by means of self-developed finite elements method [12].

The twin-roll casting module is equipped with three gauges for measurement of deformation force during the process. Two hydraulic capsules capable to fix force to 50 kN are put between fixed roll chuck and body. Sensor for measurement of force to 120 kN is installed under adjusting screw of slidable roll from the furnace. All sensing instruments are connected to computer. Thus, it is possible to observe value of force acting on the rolls during cast-rolling.

The designed experimental twin-roll caster was put in operation by a producing strip ~2.5 mm thick from pure aluminum which chemical composition corresponds to alloy AA 1070. Melting induction high-capacity furnace was not used, metal weight of first smelting operations was 10-15 kg. The photo of plant after trial run is shown in **Figure 5**.

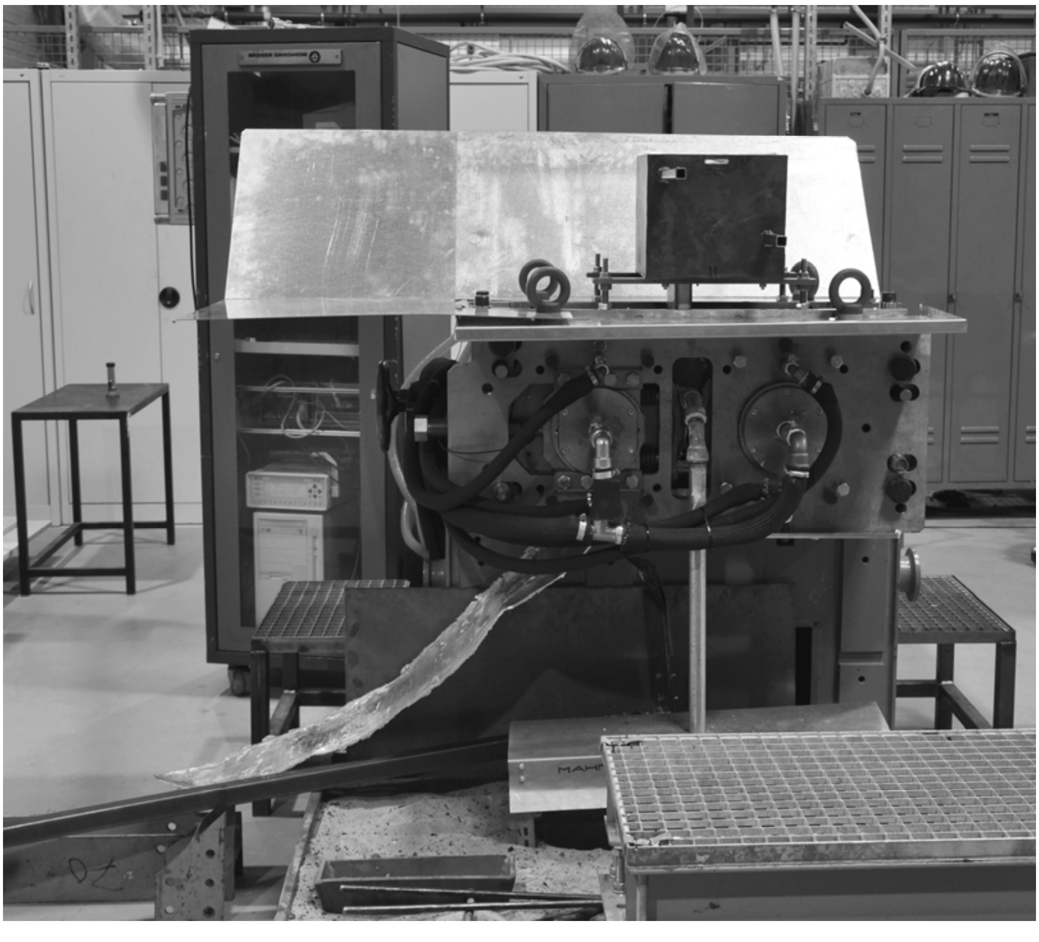

Figure 5. Experimental twin-roll caster

Table 2. Principal characteristics of designed experimental twin-roll caster

Characteristic, unit of measurement	Value
Outer diameter of steel compressive rings, mm	370
Wall thickness of steel compressive rings, mm	15
Length of roll work section, mm	200
Distance between set rolls, mm	10
Maximum weight of melt, kg	150
Motor (output) power, KW	4,4
Maximum casting rate, m/min	8
Maximum delivery volume of cooling liquid, l/min	112
Proposed range of produced strip thickness, mm	1-5
Proposed materials for cast-rolling	aluminum, magnesium, steel, bimetals

Conclusions

Experimental twin-roll caster for production of nonferrous metal and steel thin strips was designed and commissioned due to cooperation of Metal Forming Department (National Metallurgical Academy of Ukraine) and Institute of Materials Science of Leibniz Universitaet Hannover (Germany). This equipment has a number of advantages as compared to the existing devices for sheet production directly from the melt between two rotating crystallizers. In particular, great uniformity and intensity of strip cooling in water cooled shells is provided, deforming ability of the plant as a whole exceeds possibilities of similar known plants, casting direction can change from vertical to horizontal including intermediate values, etc.

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* Published in Russian

Received August 25, 2010

Экспериментальная установка валковой разливки-прокатки тонких полос

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Описаны особенности конструкции и основные технические характеристики экспериментальной машины валковой разливки-прокатки собственной разработки, предназначенной для получения полос толщиной 1-5 мм и шириной до 200 мм из цветных металлов и сталей. Проведен анализ известных из литературы данных об устройстве существующих лабораторных установок аналогичного назначения. На его основании сделаны выводы о преимуществах и потенциальных возможностях машины предлагаемой конструкции.