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CHOICE OF HEAVY BLOOMING MILL VERSUS CONTINUOUS CASTING : TECHNICAL AND ECONOMIC COMPARISON[1]

by

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SUMMARY

In the conventional casting process, the liquid steel is poured from the ladle into a number of individual ingot moulds. After this discontinuous casting operation the solidified ingots are separated from the moulds and transferred to soaking pits or pushertype furnaces where they are reheated to rolling temperature. Thereafter the ingots are rolled in a blooming or slabbing mill to semi-finished products, while the moulds are transported back to the steel works.

In continuous casting, on the other hand, the liquid steel is tapped from the pouring ladle continuously into one or several strands. The heart of this pouring operation is the water-cooled, open-ended and oscillating mould within which the shell of the continuously emerging strand begins to solidify. In a single production step, without costly intermediate operations, accurately dimensioned and homogeneous semi-finished products are turned out by a process which is mechanized and largely automated.

The conventional ingot casting/primary mill route involves considerable cost sources. The numerous material transfers and intermediate steps are hardly suited to meet the demand of rationalisation in the steel industry, mainly in view of future automation. With continuous casting the two independent functions "casting" and "primary rolling" are combined into one simple process, and all transfers and relevant equipment can be dispensed with; no moulds and no ingot pits or pusher furnaces are required.

The authors review in their comparison between the traditional ingot casting/primary mill route and the continuous casting route, steelworks utilizing continuous casting installations mainly or

exclusively, the economics, and add some continuous-casting machine design criteria and metallurgical considerations together with a brief description of a large 2-strand high-rate slab casting machine and its operation. Mention is also made of the training of operators which plays an important role in decision making.

It becomes evident that mainly the combination of oxygen steelmaking with continuous casting installations allows the by-passing of the ingot casting pit and the slabbing mill with the auxiliary facilities required. Furthermore, because of the considerable yield saving, a substantial gain will be obtained by lower conversion costs from liquid steel to the final product. The present trend is towards small and large "continuous casting works", whereby no conventional casting methods at all are applied. Today's continuous-casting machines are well within the requirements for equipment that will operate reliably in a steelworks environment with ordinary operating and maintenance personnel. With further developments, besides incorporating the latest developments with respect to producing high-quality end products, the requirements of simple operation and maintenance are being considered as well. By means of coordinated on-machine and theoretical classroom training during the building and commissioning period, the crews became familiar with the process and its detail operations in time, resulting in short and smooth start-up periods.

Contents

1. Comparison between the traditional ingot casting/primary mill route and the continuous casting route

In the conventional casting process, the liquid steel is poured from the ladle into a number of individual ingot moulds. After this discontinuous casting operation, the solidified ingots are separated from the moulds and transferred to soaking pits or pushertype furnaces where they are reheated to rolling temperature. Thereafter the ingots are rolled in a blooming or slabbing mill to semi-finished products, while the moulds are transported back to the steel works.

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The operations involved in the two processes is represented in Table 1 and illustrated in Figure 1.

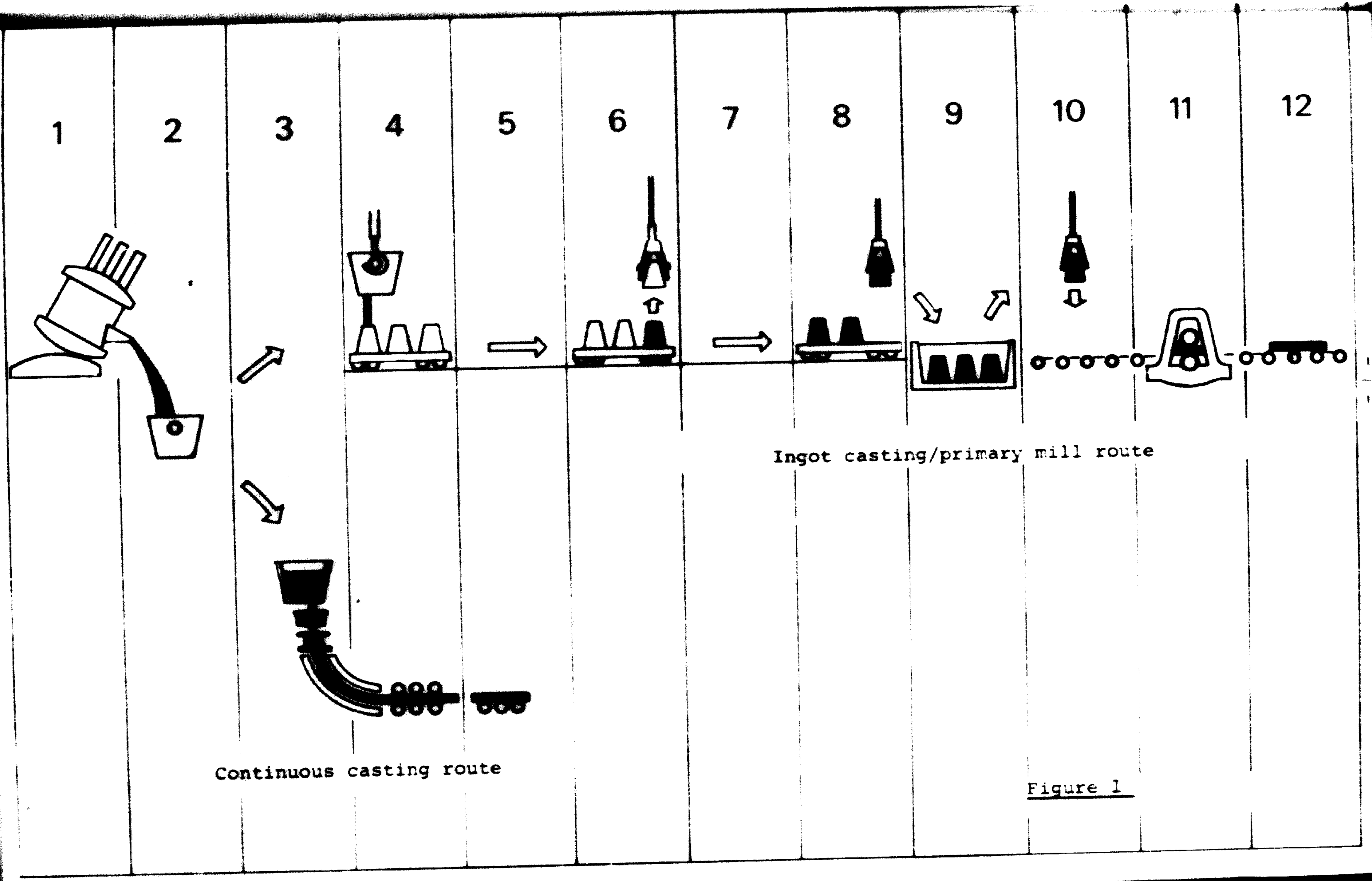
Ingot casting/Primary Mill	Continuous Casting
1. Furnace tapping	1. Furnace tapping
2. Ladle transfer to casting pit	2. Ladle transfer to casting platform
3. Casting into moulds	3. Continuous casting
4. Transfer of the ingot moulds to the stripper yard	4. Subdividing of the cast strands
5. Stripping	5. Transfer of the cast material to the rolling mill
6. Transfer of the ingots to the pit or pusher furnaces	
7. Ingots placed into pit or pusher furnace	
8. Heating the ingots	
9. Transfer of the ingots to the primary mill	
10. Primary rolling	

11. Grinding of the rolled products	
12. Transfer to the rolling mill	

Table 1

Compared with the conventional casting and rolling of ingots, continuous casting provides substantial economic advantages:

- lower investment cost
- reduced space requirement
- fully continuous and automated operation
- more homogeneous product
- higher yield in terms of semi-finished products
- fewer processing steps
- lower conversion costs
- fewer employees, working under better conditions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Ingot casting/primary mill route
Continuous casting route

Figure 1

The yield of plate, sheet, and coils is improved by as much as 10 % when continuous casting is applied, resulting in a significant increase in available steel capacity, and lower production costs.

All types of commercial steels, e.g. for rebars, wire rope, cold heading, sections, plate, tinplate, double-reduced tinplate, deep-drawing steel, galvanized sheet, plate steel (e.g. for pipe-lines), etc., are successfully and profitably produced on continuous-casting plants. Products made from continuously cast slabs are more uniform in grain size than conventionally cast material, and have a lower rejection rate.

Casting machines are operated in connection with open-hearth, Kaldo, electric arc furnaces, and oxygen converters. The heat sizes range from 6 to 350 t. The continuously cast steels are killed grades and for previously conventionally cast semi-killed and rimming qualities substitute killed steels have been developed.

Three groups of single- or multistrand conti-casters are in operation:
- Billet machines producing dimensions up to approx. 160 x 160 mm.
- Bloom machines designed for bigger cross-sections (largest bloom cast at present 620 x 430 mm).
- Slab installations built for sizes up to 2300 x 305 mm.

In the big steelproducing countries like the United States of America, USSR, Japan and the FR of Germany, and in addition Italy and Spain, continuous casting is applied to a larger proportion than in areas which are in the process of increasing their steel capacity, as for instance in Latin America or South-East-Asia.

To steelworks in countries with rapidly growing industrialization continuous casting offers special advantages. Billet machines of simple design, easy in operation and maintenance, are available at reasonable investment costs. The number of small steel plants consisting of but one or several electric arc furnaces, one or two continuous billet casters with 2, 3, or 4 strands, and an adequate rolling mill is steadily increasing. The production programme of these mini-plants comprises generally reinforcing bars, smaller sections, or wire rod. The same trucks supplying the mill with scrap deliver also the products to the customer.

Considering small semi-integrated steel plants, typical features, technological and economical advantages of the combination of electric arc furnaces, continuous-casting installation and a merchant mill are:
- Low capital investment
- Minimum in-plant distances
- Specialized production programme
- Delivery limited to a clearly defined sales area
- Short delivery times.

The continuously cast billets are ready for further processing to final products, whereas the stripping and transportation of the conventional cast ingots needs much more handling.

Reports on slab, bloom, and billet quality demonstrate customer acceptance for a wide variety of end-products. High-speed casting of sheet steel leads the way in associating BOF production and the sequence casting technique to realize an uninterrupted operation.

The practical results obtained in the field of continuous casting during the first years of this decade confirmed that
- the building of large steel plants without blooming and slabbing mills can be recommended;
- already a great number of continuous-casting plants is in operation to absorb the entire output of steelworks;
- for various applications the market is specifying sheets originating from continuous casting only, since the end-products exhibit a high degree of metal uniformity; e.g. the stampability for deep-drawing parts is regular over the entire coil length because of the very small variation in the mechanical properties compared to material made from ingots.

2. Steelworks utilizing continuous-casting installations mainly or exclusively

The percentage of continuously cast steel related to the total world steel production is growing progressively, so that it can be anticipated that by 1975 the world continuous casting capacity could reach 200 million tons. The growth rate depends on a major extent on the installation of continuous-casting works, replacing conventional blooming/slabbing mills in new integrated steel plants.

The interest in the installation of continuous-casting equipment is turning towards big continuous-casting works with yearly capacities of 4 to 6 million tons. The economical aspects of such large plants compare favourably with conventional teeming/slabbing steelworks, mainly in view of the considerably lower conversion costs.

Small steelworks operating casting machines without ingot pit

The first application to operate a steelplant without the classical ingot facilities occurred in smaller works equipped with arc furnaces, whereby billets were continuously cast. The definition small steel plant refers generally to an annual production of less than 300,000 t; in the United States a plant with a raw steel capacity of 400,000 short tons per year is still regarded as "mini style of steel-making".

The first LD shop working with continuous casting only began operating 1965 at Elfouladh, Tunisia; the melt shop comprises two 12 t converters and two twin-strand billet casting machines (sections 95 and 110 mm square). The yearly output is approx. 80,000 t and is processed to rod, bar, wire, and light sections.

Table 2 reveals some examples of companies pioneering this way since the first part of the last decade.

Plant	No ingot pit since	Heat size (t)	Section cast (mm)	Final product
Paderwerk, Germany	1960	20	160 octagonals	Tubes
Barrow Steel, England	1961	20	50 - 100 sq.	Bars, Angles
Ybbs, Austria	1961	8	100 sq.	Rebars
Del Besos, Spain	1963	20	80, 100, 120 sq.	Rounds, Angles
ORI, Italy	1966	35	115 sq.	Rebars

Table 2

Since several years the operation without an ingot pit is normal practice, whereby Table 3 indicates some examples of mini-steelworks recently gone on stream.

Company	Start-up	Steel-making	Capacity t	No. of strands	Billet size mm	Processing
HyLSA, Puebla Works, Mexico	1969	E.F.	60	2 x 4	100	Bars, wire rod
Siam Iron & Steel, Thailand	1969	E.F.	35	3	100	Bars, wire rod
Adriasider, Yugoslavia	1970	E.F.	20	2	100	Bars, wire rod
Köverhar, Finland	1971	B.O.F.	50	2 x 4	100	As cast billets sold
Hamburger Stahlwerke, Germany	1971	E.F.	80	2 x 4	120	Bars, wire rod

Table 3

Medium-capacity steelworks operating with continuous casting only

1962, Shelton Iron & Steel, England, decided to embark in a modernization programme by installing 55 t Kaldo furnaces and 4 continuous casting machines. The plant started to become operative 1964 and was the first at this time for such a tonnage of 350,000 t/year. The casting programme comprises blooms and slabs; end products are besides medium sections and channels, also universal beams, universal columns, which require large as-cast sections, e.g. 620 x 430 mm, 510 x 405 mm or 460 x 355 mm, representing still the biggest thickness cast continuously today.

The continuous-casting process for carbon steel billets and blooms expanded quite rapidly and is applied today in many small and medium sized companies. Dependent on the number of furnaces, their cycle time, the heat size, and the sections to be cast, one or more single or multi-strand machines are operated.

Large-tonnage continuous casting of slabs

The development of the optimum operating techniques associated with the respective design features for slab casting started with the production of continuous casting of plate grades. For wide strip grades a plurality of slab casters is in satisfactory operation, but generally a fraction only of the entire steelworks output is cast by this method presently, whereas the remainder is processed conventionally.

3. Economics

For a meaningful comparison of continuous casting with the conventional ingot casting and primary rolling method it is necessary to select a few standard ways of operation, and establish the respective cost comparison as a guide line. Since today's steel industry utilizes a great variety of different manufacturing procedures it is unavoidable that for each individual case a specific study is required where, however, the comparison presented below gives some guidance.

To Table 4: Production of billets

The capacity is assumed to be about 800,000 tons per annum of commercial steels.

The continuous casting of billets in a cross-section (80 to 120 mm sq.) which can be rolled in one heat to final rolled products (including wire bar 5.5 mm Ø) is not well suited for large ladles above approx. 120 tons. As a consequence the cost comparison should also be made for the production of blooms in a continuous-casting machine and by conventional ingot pouring and rolling.

To Table 5: Production of blooms

The capacity is assumed to be 1.2 mio tons per annum.

To Table 6: Production of slabs

The capacity is assumed to be 1.5 mio tons per annum.

Possibility continuous casting offers concerning step-by-step increase in production

If a heavy breakdown mill cannot from the beginning of operation handle the rated output, the machine is charged with proportionally too high overheads. Continuous casting allows with the staggered installation of a number of machines to adjust the equipment capacity to the increased steel requirement but always making most economical use of the equipment installed (Figure 2).

Table 4:

Form for determining individual cost figures for continuous-casting projects comparing conventional method and equipment with continuous casting

Example 1: Production of billets, capacity assumed approx. 800,000 tons/year

	Conventional pouring route			Continuous-casting route		
Steelmaking *) Insert your figures	Liquid steel –	*)	100 0%	Liquid steel Additional costs to suit continuous casting	*)	100% max. 5%
	Total		100	Total		max.105%
Conversion *) Insert your figures	Ingot casting/ Stripping Soaking pits Breakdown rolling Reheating Billet mill	*)	100% 100% 100% 100% 100%	Continuous casting – – – –	*)	115% 0% 0% 0% 0%
	Total			Total		
Capital expenditure	100%			45 - 55 %		
Yield factor	approx. 83%			approx. 97%		

Table 5:

Form for determining individual cost figures for continuous-casting projects comparing conventional method and equipment with continuous casting

Example 2: Production of blooms, capacity assumed approx. 1.2 mio tons/year

	Conventional pouring route			Continuous-casting route		
Steelmaking	Liquid steel	*)	100%	Liquid steel	*)	100%
***) Insert your figures**	-		0%	Additional costs to suit continuous casting		max. 5%
	Total		100%	Total		max.105%
Conversion	Ingot casting/ Stripping	*)	100%	Continuous casting	*)	110%
***) Insert your figures**	Soaking pits		100%	-		0%
	Breakdown rolling		100%	-		[illegible]
	Total			Total		
Capital expenditure	100%			65 - 75%		
Yield factor	approx. 87%			approx. 96%		

Table 6:

Form for determining individual cost figures for continuous-casting projects comparing conventional method and equipment with continuous casting

Example 3: Production of slabs, capacity assumed approx. 1.5 mio tons/year

	Conventional pouring route			Continuous-casting route		
Steelmaking ***) Insert your figures**	**Liquid steel** -	*)	100% 0%	Liquid steel Additional costs to suit continuous casting	*)	100% max. 5%
	Total		100%	Total		max.105%
Conversion ***) Insert your figures**	**Ingot casting/ Stripping** **Soaking pit** **Slabbing mill**	*)	100% 100% 100%	Continuous casting - -	*)	105% 0% 0%
	Total			Total		
Capital expenditure	100%			80 - 90%		
Yield factor	approx. 85% (for killed steel)			approx. 95%		

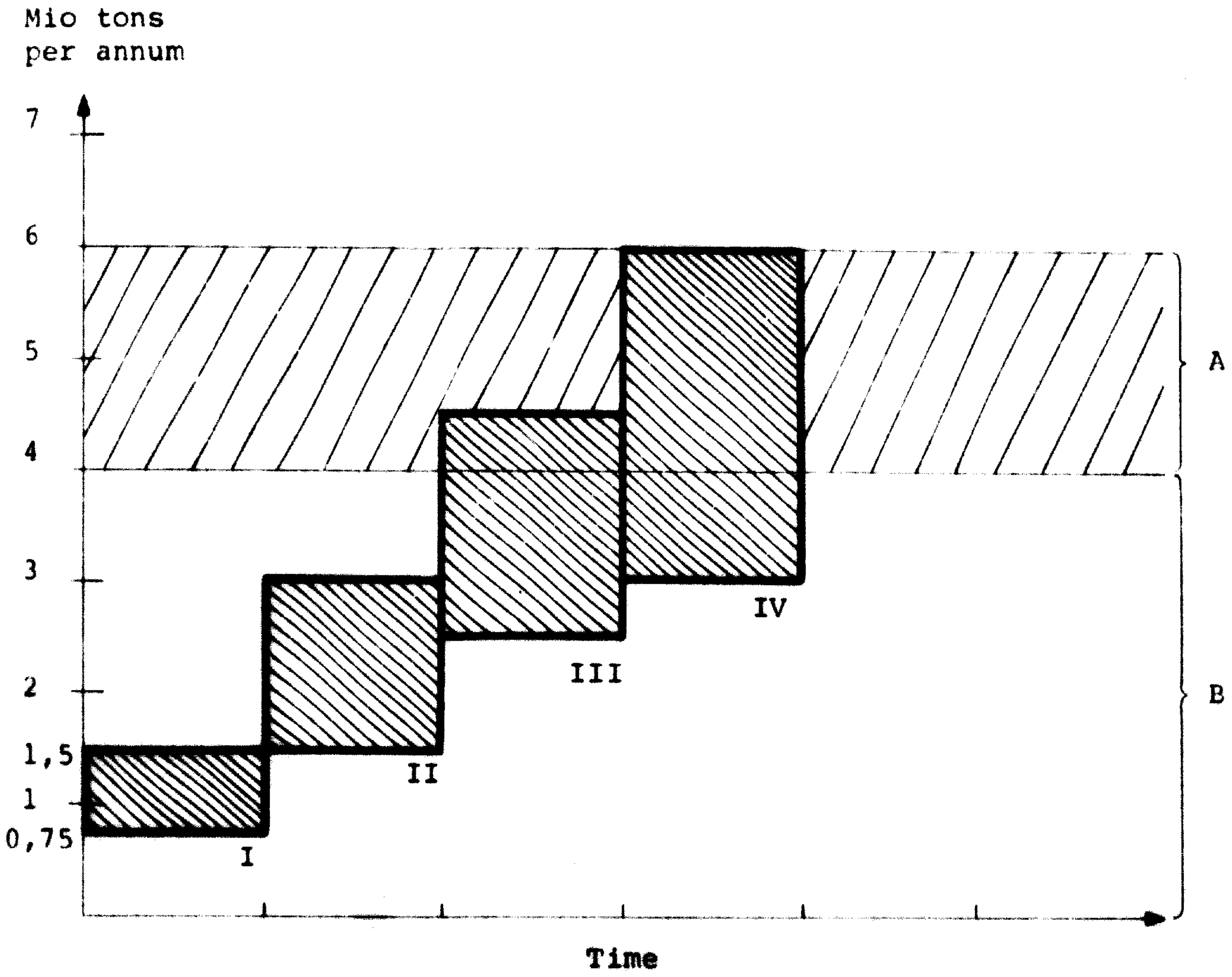


Figure 2: Possibility continuous casting offers concerning step by step increase in production

Legend:

A : Economic range of blooming/slabbing mill

B : Non-economic range of blooming/slabbing mill

I : Capacity continuous-casting machine no. 1

II : Capacity continuous-casting machines nos. 1, 2

III : Capacity continuous-casting machines no. 1, 2, 3

IV : Capacity continuous-casting machines nos. 1, 2, 3, 4

(Twin-strand slab-casting machines, capacity varying with slab cross-section range and ladle capacity)

4. Some continuous-casting machine design criteria and metallurgical considerations

Continuous casting of steel comprises in a broad sense the control or the attempt to control the liquid phase from steelmaking until entry into the mould, the liquid/solid phase (forming of the strand until complete solidification) and the further handling of the strands after solidification.

The properties and the dimension of continuously cast products ready for rolling are governed by:

- the condition of the liquid steel supplied to the caster
- the concept of the various machine components being part of the casting apparatus which absorbs liquid steel at its entry to deliver solidified subdivided cast strands at its exit
- the range of casting parameters allowable
- the scope of equipment and space available for handling and treating the strand prior to rolling.

One prerequisite for a good casting performance is the health of the liquid steel fed to the mould. It is presupposed that the steel is neither overblown nor exceeding the amount of trace elements permissible for a specific grade.

Depending on the ladle size, the transfer time from the furnace to the casting plant is of importance. In case of long transfer times (tolerable for ladle sizes over 100 t) gas flushing immediately after the tap is necessary; thus 30 to 40 minutes can elapse before the cast starts and still the complete steel content in the ladle can be emptied. More flexibility is available when using ladles equipped with sliding nozzles because of the possibility to preheat the lining. Reference is also made to vacuum treatment serving both for temperature equalizing and better control of quality for a specific range of grades.

4.1. Design components affecting the liquid steel

Present-day casting machines operate with a tundish serving as metal distributor, separator, and buffer for sequence casting. The open-stream supply of steel from the ladle to the tundish is common practice. When casting special grades to restrict the contamination of the liquid steel a shroud is provided protruding into the tundish. Additional protection can be realized by supplying an inert gas into the gap between the ladle stream and the refractory.

Cold model studies have been undertaken to evaluate the ladle/tundish/mould configurations on their effect on the inclusion content of the cast product. Calculations indicated that large inclusions in the tundish metal are from slag entrained by the ladle stream entering the tundish, coagulation and inclusion growth has also to be taken into account; apart from the residence time of the steel in the tundish, a major source of the inclusion content is the aerial oxidation of the liquid steel surface in the mould.

The metallurgical design concept of the tundish, which represents the last metallurgical tool prior to the beginning of solidification of the strand, is characterized as follows:

- a vessel with a capacity representing a 3 to 5 minutes throughput of the strands it supplies with steel, to establish a sufficient residence time, a sufficient buffer for sequence ladle casting.
- metering nozzles in the case of open-stream casting, stoppered or slide gate nozzles; the latter insure a steady flow rate.
- ceramic bodies protecting the steel from contamination with air and protruding below the metal meniscus in the mould associated if necessary with an inert gas supply through the stopper head to control the steel flow emerging from the submerged refractory orifices. This has been tried successfully when casting high-quality slabs whereby the argon passed through the tundish stopper head.

- the tundish car or turret comprises a lowering and lifting device which serves also to locate the orifice exits of the submerged refractory body at the optimum distance below the meniscus.
- to change the tundish on the fly, a time of less than one minute is realized; the time limit being set forth is necessary because with sequence casting of wide slabs the solidified shell retracts from the mould wall when the metal supply is interrupted for a longer period. Another method is to change the pouring tube only, whereas the tundish remains in situ.
- a vessel to maintain the heat of the steel above liquidus temperature. The tundish lining is preheated prior to the cast. Besides the classical solution, reference is made to the graphite-rod tundish heating.

4.2. Design components affecting the strand until complete solidification

The design of the water-cooled copper mould governs the shape, solidification rate, and quality of the steel shell formed. Main factors to be considered in the mould design are:

- shrinkage of the steel, the mechanical properties of the strand below solidification temperature.
- friction between strand and mould (lubrication by a vegetable oil or slag powder).

resulting in

- preset mould geometry
- specific mould material
- heat removal system
- preset mould lubrication.

For billet and bloom sections up to 190 mm sq. tubular moulds are used, whereas larger dimensions have been cast 10 years ago with block moulds and at present with built-up moulds. The heat removal, beside of a design allowing an optimum water velocity, mould stability, and adequate cooling surface depends also to a major part on the water quality. It is well known that lime layers decrease the heat removal, resulting in higher mould-wall temperature and deterioration of mould geometry. The design of the mould as well as the selection of the mould materials has to take care of the thermal expansion of the copper plates. The plate moulds are for many applications adjustable whereby the mould taper can be preset depending on casting speed, strand width, and steel grade to be cast.

The properties of the copper are to be considered with a view to having the recrystallisation temperature sufficiently high. The aim of an optimum mould design (heat removal rate, shape stability, length) is to obtain at the exit of the mould a solidified shell of sufficient uniform thickness to withstand the combined mechanical and thermal stresses. Of importance in this respect is the distance between bottom of the mould and the top of the strand guide, when casting larger sections. In addition, the alignment of the mould with the strand guide and the oscillation performance have major influence on a breakout-free operation.

Lubrication of the strand, formed within the mould, is necessary and one way to realize it is the remote control of the rapeseed oil flow; when the casting operation is performed by adding slag powder or slag pellets on the metal meniscus, metering devices can be installed. The aim of adding lubricants is to reduce the friction between strand and mould; friction measurements have been made and indicate the different behaviour of various synthetic slags added to the mould.

The layout of the strand guide for wide-strip slab casters is designed for higher casting speeds, because with increasing casting speeds the surface condition of the cast strand is improved. Thus with 100 % scarfing, a method applied for today in some shops casting products for cold-rolled strip, the rejects due to scab defect ranges only around 0,5 %.

The conditions to be established for higher-speed slab casting, i.e. a withdrawal speed exceeding 1.2 m/minute, comprise special design features for

- mould
- strand guide below the mould
- withdrawal unit
- supporting elements behind the withdrawal unit.

The entire machine geometry has to be stable, either a true vertical axis in case of a pure vertical caster, or an ideal arc of a circle in case of a curved-type caster.

Calculations and theory are the skeleton of future development but tests are the blood to make these theories work, to rectify them if necessary. Three examples demonstrate practical investigations how machine components influence the solidification.

- The correct primary cooling in the mould insures a stable solidified strand shell at the mould exit and a skin sufficient uniform in thickness. E.g. uneven shell thickness, insufficient mould taper, too large a distance uncooled, and unsupported between mould and first strand supporting elements may cause breakouts.

- The secondary cooling immediately below the mould (mould spray, corner spray) is absolutely necessary for a breakout and bulging-free operation. The intensity, the spraying method are of influence to the temperature distribution within the strand and the quality of the cast product. The results of the secondary cooling pattern can best be detected by positioning a plurality of thermo-couples positioned in ceramic tubes extending over the dummy-bar head.

  Associated with the secondary cooling is for large dimension the support of the strand shell to avoid deformation of the shape because of bulging. The classical solution for supporting a partly solidified slab are rollers assembled in a roller apron. In case of high casting speeds the roller spacing immediately below the mould would have been very short and in addition supporting rolls should be considered. This led to the development of cooling plates and recently of cooling grids. The cooling grid, made of cast iron, supports the strand below the mould and the windows in the grid allow to use full-cone nozzles; this enables uniform cooling intensity and in addition practically all the unsupported elements of the wide slab faces are sprayed with water.

- The withdrawal unit for a curved-type machine is mostly located on ground floor, and Figure 3 indicates the history of the withdrawal straightener design. Solution 1 and 2 necessitate complete solidification of the slab at the exit of the roller apron and the tangent point respectively. In contrast to plate grades, which require for quality reasons complete solidification before the tangent point, low-carbon strip grades can be produced with a liquid core extending into the horizontal. Solution 3 demonstrates one design of a multi-roll withdrawal unit with a roller spacing small enough to prevent harmful bulging during operation and standstill.

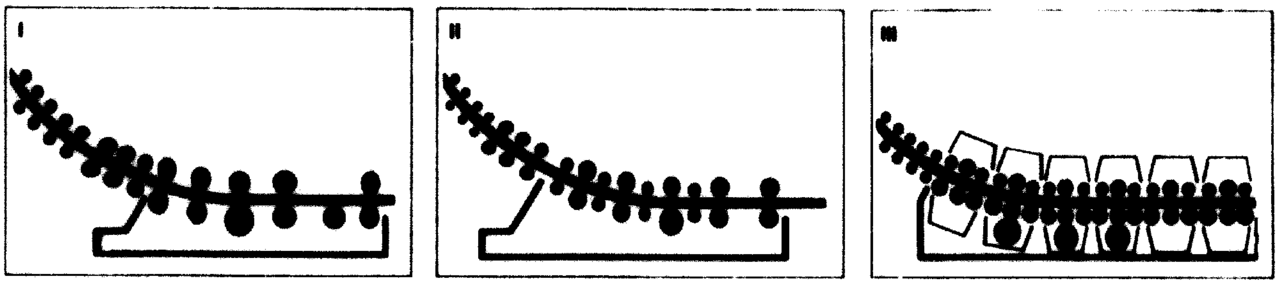


Figure 3

Since for wide slabs produced at high speeds a ratio of spray length to liquid core length of approximately 0.6 is contemplated, the provision for high-intensity spraying in the withdrawal unit is provided.

The shape of the strand being influenced by the design of the withdrawal equipment, excessive hydraulic pressure leads to deformation of the cast strand; the rolling action caused by small-diameter rolls must be limited to a fixed value; mechanical spacers, restricting the downwards stroke, will give an end product with sufficient uniformly reproducible thickness.

Associated with the design to achieve optimum metallurgical conditions is the proper arrangement of sensing and detecting devices with computer exits to control and rectify during operation,

- the strand surface temperature around its perimeter at various levels,
- the spray cooling to achieve the desired solidification profile.

Whereas the thickness control within the straightener has already been discussed, the primary shape control before the strand entry in the withdrawal unit is of similar importance. Movable disc-type sensor rolls detect off-shape conditions, the respective signals being used in a closed loop system to adjust the operational parameters, resulting again in the desired strand geometry.

4.3. Design components after complete solidification

The in-line cutting requirement, consisting of gas torches for slabs, operated automatically, subdivide the strand with a tolerance in length of plus/minus 10 mm for torch-cutting. For a short cut-length required occasionally for plate mills, even the dual-torch cutting does not permit in-line operation.

Off-line cutting operation refers not only to the cutting of the slab over the width, but also to the longitudinal cutting of slabs.

The equipment for industrial longitudinal cutting consists of either a movable torch car or a stationary unit. The requirement for such equipment is justified because the evaluation of the cut slabs showed good symmetry of the strips rolled and in addition the ultrasonic test of the material from the narrow face area (106 x 520 x 4600 mm and 106 x 390 x 4600 mm rolled to 2.2 mm respectively 1.4 mm strip) did not reveal any defects. The slab center strips showed for 4 m of strip length a small reflection on the oscillograph; beside this quoted defect no differences compared to the outside strip in any condition (surface, edges, etc.) have been found.

Scarfing affects the shape of the cast strand. Plate-mill products generally require only spot scarfing to remove defects; this is normally accomplished by hand spot scarfing.

For commercial-quality strip-mill products, hand spot scarfing of perhaps 8 - 10 % of the slab surface area would be sufficient for about 80 % of the end-product requirement. The balance could require 100 % skinning.

In some plants 100 % scarfing of all slabs is practiced. At other installations the practice is to test stripe with a hand scarfing torch. Based on the inspection of these test stripes, a decision is made on whether to 100 % wash the surface or spot scarf only the obvious surface defects.

Cold scarfing has several advantages over warm scarfing and hot scarfing. The slabs can be selected for conditioning on the basis of test hand striping, a procedure resulting in yield improvements. The scarfed surfaces are clean and relatively easy to inspect. Compared to hot scarfing, the cold scarfing procedure requires considerable yard area and handling facilities. Assuming an output of a continuous casting plant of 40,000 tons/day of slabs 1525 by 255 mm, 760 mm long (approximately 30 tons/slab) result in approximately 133 slabs/day. This in turn gives 22 piles of 6 slabs each. The area requirement is approximately 160 by 40 m taking into consideration a two days production of slabs being stored. Forced cooling of slabs for soft steels is applied in order to improve turn-around time. In addition, a descaled surface facilitates the detection of surface defects.

5. Brief description of a large 2-strand high-rate slab-casting machine and its operation

As an example which in principle also stands for bloom and large billet casters, we give a brief description of the operation and some technical details of a large 2-strand slab machine utilizing sequence casting operation.

From this description it becomes evident that the operation of such large units concentrates to but a very few different key points as is the case with small billet machines. Operation is controlled and supervised from the central control room on the casting platform and from an additional, connected control room for the discharge side operations such as dummy bar handling, withdrawal- and straightening mechanism, cutting and slab handling.

The central control room located on the casting platform comprises the instrumentation for:

- steel temperature in ladle and tundish,
- strand surface temperature,
- casting speed,
- automatic level control,
- mould, secondary and machine cooling-water quantity,
- total power consumption, etc.

Casting time, strand length, ladle and tundish weight are indicated continuously.

5.1. Liquid steel side of the machine

Gas rinsing in the ladle

Temperature equalizing of the liquid steel in the ladle became standard practice with continuous casting. It ensures trouble-free operation over long casting times. The gas rinsing facilities usually are installed at the rear of or somewhere else close to the casting machine. During gas rinsing the steel temperature is checked, and steel samples are taken for spectrographic analysis.

Ladle transfer to casting position

After gas rinsing the ladle is brought by crane to the casting platform. For sequence casting operation today, ladle cars or turn-tables are used instead of the previous ladle stands. The full ladle is placed on the empty ladle car or on the empty swivel arm of the ladle turn-table, and subsequently brought into its position above the tundish.

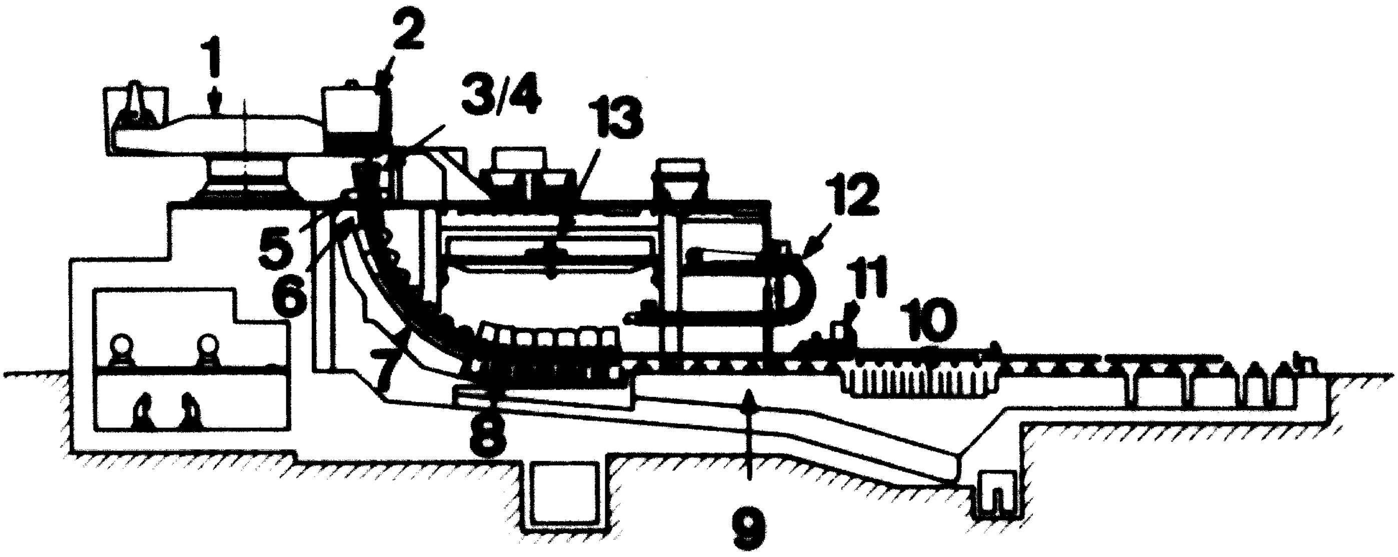


Figure 4

Cross-sectional sketch:

1 Ladle turn-table
2 Ladle
3 Tundish
4 Tundish car
5 Mould
6 Cooling plates or grids
7 Roller segments, secondary cooling zone
8 Roller-segment-type withdrawal and straightening zone
9 Intermediate roller table
10 Cutting roller table
11 Cutting machine
12 Dummy-bar storage
13 Auxiliary hoist for roller segment maintenance

Ladle turn-tables ensure good accessibility to the casting area which is a prerequisite for safe, smooth, and troublefree operation. Instead of ladle stoppers more and more slide gate valves are used.

Tundish

One common tundish is used to supply steel to both moulds. Its dimensions allow continuous uninterrupted steel flow to the moulds during ladle change. With slab casting the technique utilizing pouring tubes instead of open-stream nozzles today is usual practice.

As is the case with the casting ladles, stoppers in the tundish are being replaced by slide gate valves.

Tundish cars or turrets

The tundishes are placed on cars or on swivel arms in order to allow smooth and fast exchange. The tundish preheating stations are arranged accordingly.

5.2. Solidification

Moulds

Today most moulds for slab casting are adjustable copperplate units for fast change without time-consuming alignement in the casting position and without manual coupling of the water connections.

The use of casting flux powders with slab casting today is usual practice.

Modern high-rate slab-casting machines exhibit a series of automatically controlled operations; automatic mould-level control is one example, it allows operating the machine with reduced crews.

APS instrument block for recording the heat balance of continuous-casting moulds

One result on the way to process control with continuous casting is the APS instrument block for recording the heat balance of continuous-casting moulds.

The group of instruments provides metallurgical and operational data at an early stage of the casting operation. While the recorder of the heat-removal rates primarily indicates the transient heat-transfer conditions between strand and cooling water in a clear and direct form, the heat-removal counter is suited particularly for studying the process. The counter enables the amounts of heat removed during typical casting periods to be read off in simple fashion, so that the average heat-removal rates can be determined. The average heat-removal rate reflects the interaction of individual process parameters, such as the temperature and analysis of the molten steel, the strand cross-section, casting rate, lubrication conditions, and behaviour of the strand shell in the mould etc.

The APS instrument block facilitates insight into the fundamental relationship between various process parameters such as chemical composition and temperature of the molten steel, solidification and lubrication of the strand in the mould (e.g. influence of the lubricating oil or flux powder), and quality of the strand surface (e.g. formation of cracks). Thanks to the plot of the heat-removal rate it offers further substantial operational advantages:

- Early warning of breakouts initiated within the mould
- Supervision of the casting operation; the strip chart of the heat-removal rate provides the casting foreman with a central information source.
- Monitoring the state of the mould.
- Quality control of the flux powder, etc.

Secondary cooling zone

Below the casting floor, the cooling chamber is located. The strand guide consists of individual segments which allow rapid thickness adjustment. The segment-type roller system is continued in the withdrawal and straightening unit.

Mould and first zone of the strand guide form a compact unit allowing fast and simple joint exchange. The mould frame carries the water header boxes, thus all water connections are coupled automatically when mould and first zone are set in place. Now that hydraulic holding-down of the segments, in which the cylinders absorb the ferrostatic forces, has proven itself over a sufficiently long period of time in an installation, it is to be expected that this system, which is mechanically simpler and offers important advantages in the event of faults, will be adopted generally. Driven rollers, such as required for the operation with a short dummy bar, are incorporated into the segment design.

The higher casting speeds, and the tendency to install machines for a slab width exceeding 2 m, necessitate a very close spacing of the rollers immediately below the mould. Small roll diameters require back-up rolls which are difficult for maintenance; thus rigid plate or grid support in this area is realized. In many cases the cooling grid will meet the requirements because of the potential to simplify the first zone.

Dummy bar

The adjustable Concast dummy-bar head can be used for every subsequent cast having the same strand thickness. In the mould, the liquid steel solidifies around the permanent, clawshaped dummy-bar head, which is simply tilted from the cast strand for disconnection.

Withdrawal and straightening units

The withdrawal and straightening unit consists of segments comprising three rollers each, a concept which yields good results regarding straightening quality and maintenance. The stands comprise numerous intermediate rollers as on the strand guiding segments in the cooling chamber, allowing only partially solidified strands to be supported as well. New metallurgical findings give rise to the expectation that future withdrawal and straightening units will be equipped with devices which permit particularly gentle handling of the strand in the area of residual solidification, e.g. with a hydraulic hold-down system working with full force only down to the nominal thickness of the slab, and below that with sharply reduced forces.

5.3. Operations after complete solidification

Cutting station

After completion of a cast, when the strands have left the machine, the dummy bars are restranded (with sequence casting, that means uninterrupted operation of a casting machine, these preparations have to be made after completion of a series of casts only). Subsequently, the strands are subdivided into rolling lengths.

Slab marking

On completion of cutting, the slabs are automatically tagged and identified with the cast and strand number, relevant metallurgical data, and calculated weight by Hilti markers for each strand between cut-off position and discharge roller tables.

6. Training of operators plays an important role in decision making

Modern continuous-casting machines are designed to incorporate the latest developments with respect to producing high-quality end products, but the need for simple, rugged equipment was always a major consideration. It was understood that the utilization of continuous casting in steelmaking rather than conventional ingot-pouring practice required certain adjustments relative to the demands on operating and maintenance personnel. Undue complexity and sophistication incorporated in the design of casting machines could prove to be very troublesome, ultimately resulting in poor machine performance and greater production costs.

Modern continuous-casting machines are well within the requirements for equipment that will operate reliably in a steelworks environment with ordinary operating and maintenance personnel. This fact is being proven by the daily and overall performance at many steelworks around the world.

As is the case with rolling mills and other steelworks equipment, during the building and commissioning phase the crews of continuous-casting machines have to be trained practically in order to avoid start-up troubles and to reach normal production schedule as soon as possible.

Carrying through practical on-machine training regularly since many years, Concast AG, Zurich/New York, has realized the necessity of a certain theoretical instruction in close cooperation with the customer in addition. By means of coordinated on-machine and theoretical training programmes, the crews become familiar with the process and its detail operations before the first cast takes place. The additional costs of the classroom programmes are being compensated well by short start-up times usually not exceeding two weeks.

The company therefore has carefully examined all available audio-visual education methods, and then based its basic lecture courses on a series of slide-sound programmes, split for the different types of continuous-casting machine. These basic programmes consist of the following series of audio-visual lectures:

Introduction:

- History, present state, and actual position of the continuous-casting process.
- Description of a casting machine and its main elements and functions.
- Job descriptions.

Operation of the machine:

- The casting ladle, from preheating to casting position.
- The tundish, from lining repair and preheating to casting position.
- Description of the mould.
- Preparing the mould before the cast.
- Start of a cast and operations during the cast on the casting platform.
- The secondary cooling zone.
- The discharge side of the machine.
- Completion of a cast and preparing the machine for the next heat.
- Possible failures, their reasons, hints for avoiding troubles.
- Safety devices and instructions.
- Automatically controlled operations.
- Sequential casting.
- Check-list of all detail operations.

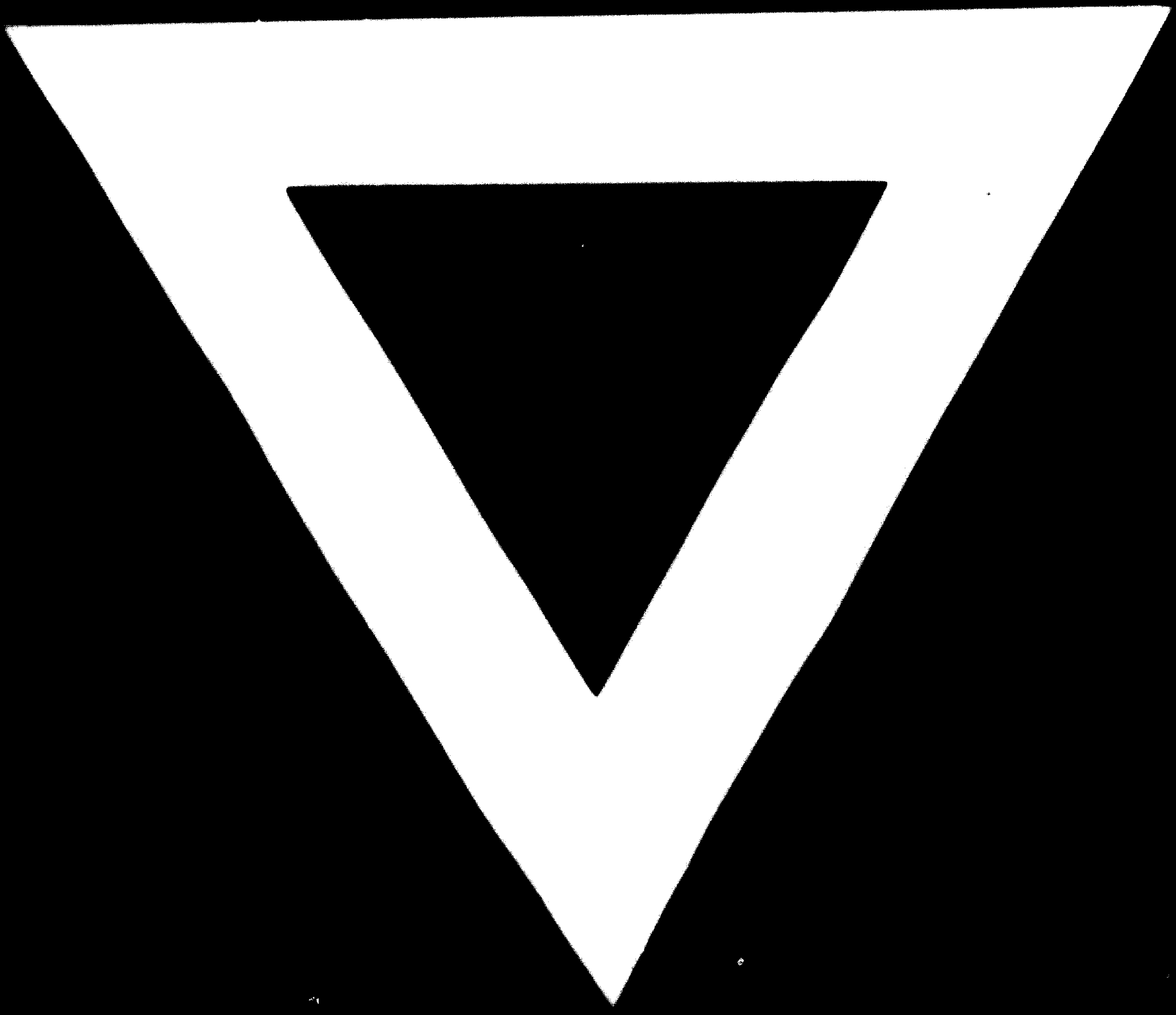
Special parts for individual personnel groups:

- Casting records
- Ladle and tundish lining
- Hydraulics
- Electrics
- Water circuits and installations
- Checks, maintenance, and repair

Methodics of instruction:

- A theoretical classroom programme consists of 20 to 30 individual parts or lectures as listed above. The basis of each lecture is an audio-visual series of 40 to 100 color slides each, synchronised with a commentary in the customer's language, 10 to 25 minutes in length. Each stage of an operation is presented in as many phases as are needed to ensure comprehension.
- Subsequently each subject is discussed thoroughly, drawing upon additional media such as films, models, drawings, photographs, operating manuals, actual machine parts or single slides from the audio-visual series.
- The on-machine practical training is incorporated into and coordinated with the programmes of the classroom lectures, thus forming the most efficient and most complete training programme available to steelworks implementing continuous-casting projects.

The basic theoretical programmes can be split or adapted and completed for special individual groups of personnel. In addition, Concast's training group is prepared to arrange special lecture programmes in cooperation with suppliers of supplementary equipment utilized within the continuous casting plant. The first of these series, produced in cooperation with Stopinc AG, Zug, is a description and working instructions for slide gate nozzles for ladles and tundishes.



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