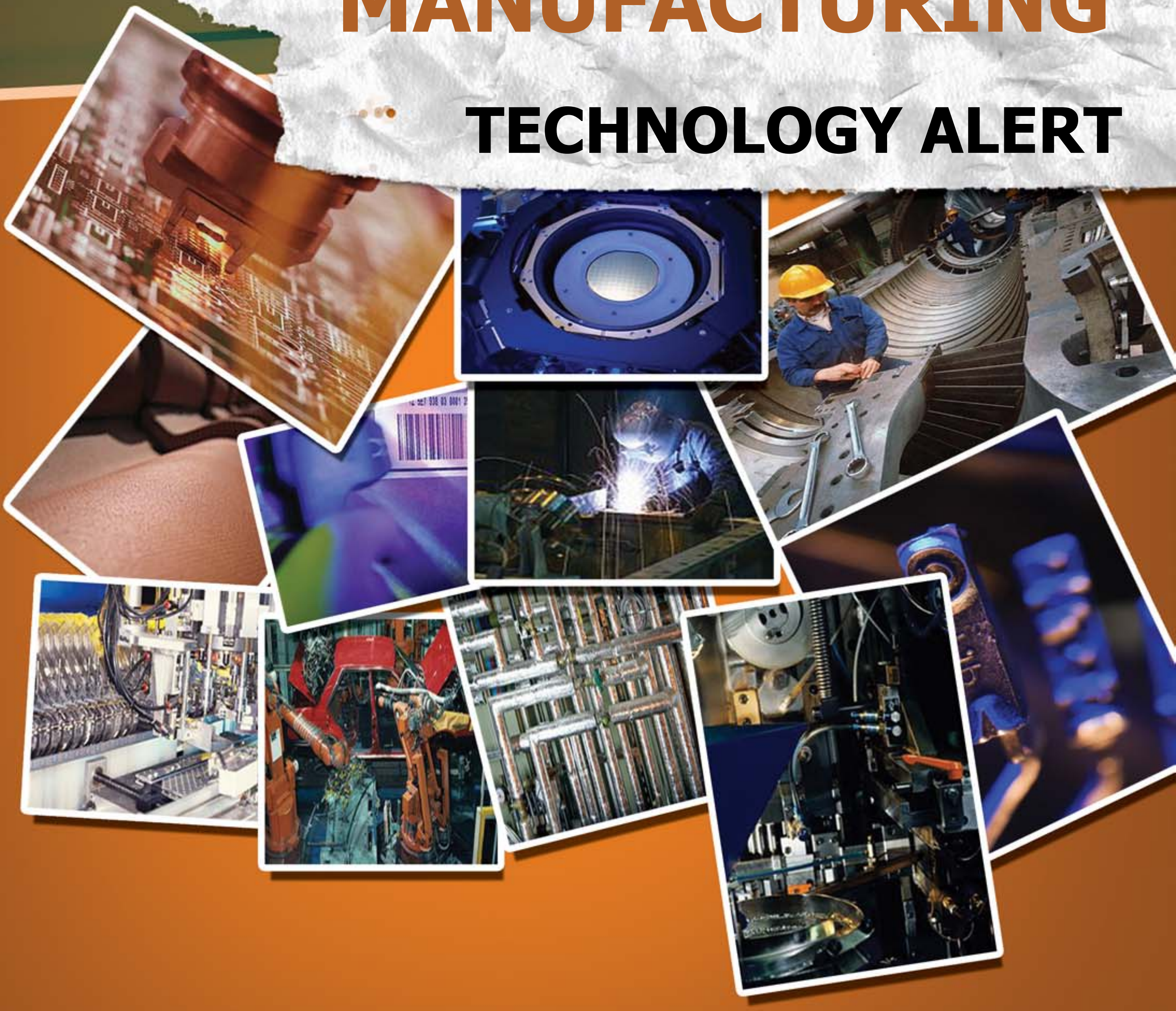
TECHNICAL INSIGHTS

ADVANCED MANUFACTURING

TECHNOLOGY ALERT



07th November 2014

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1. ELECTRIC ARC FURNACE MELTING OF METALS

Electric arc furnace (EAF) is an established and growing technology for industrial melting of metals. In the steel industry in the US, the majority (around 60% to 65%) of steel tonnage produced annually is now from the EAF. The main alternative is the fossil fuel-fired large integrated mill (iron ore and coke plus some limestone fed into a blast furnace producing high-carbon molten pig iron, subsequently processed into low-carbon steel by a Basic Oxygen Furnace) as operated by US Steel Corp. for over 100 years. ArcelorMittal is also operating such an integrated mill near Detroit, Michigan (the former Ford Dearborn steel mill).

The EAF (which has a typical capacity of 80 to 150 tons of steel per heat) benefits from its use of scrap steel for feed stock. European operators also melt direct reduced iron (DRI) pellets. In the US and other industrialized countries, there is a plentiful supply of steel scrap. In fact, the US is a net exporter of steel scrap. The scrap feed for the EAF needs to be clean and processed to keep contaminates out (such as copper wiring). Another EAF advantage is the ability to melt only when demand requires (highly flexible), unlike a blast furnace which must operate 24/7 for years at a time before refurbishment and replacement of fire brick insulation.

A typical EAF (see exhibit below) is fired by 3-phase AC power (up to 120 MVA, but 60 MVA is more typical) with 3 carbon electrodes on the furnace roof projecting into the melt chamber. Less common is the DC-type EAF, which has power capacities up to 140 MVA. The massive AC power draw is such that an electric arc furnace needs to be served by its own large power transformer and a dedicated 3-phase primary feed circuit. Any other loads on the EAF's AC circuit would suffer from flicker (distorted harmonics) and constantly fluctuating voltage, due to uneven melting activity and related undulating current draw.

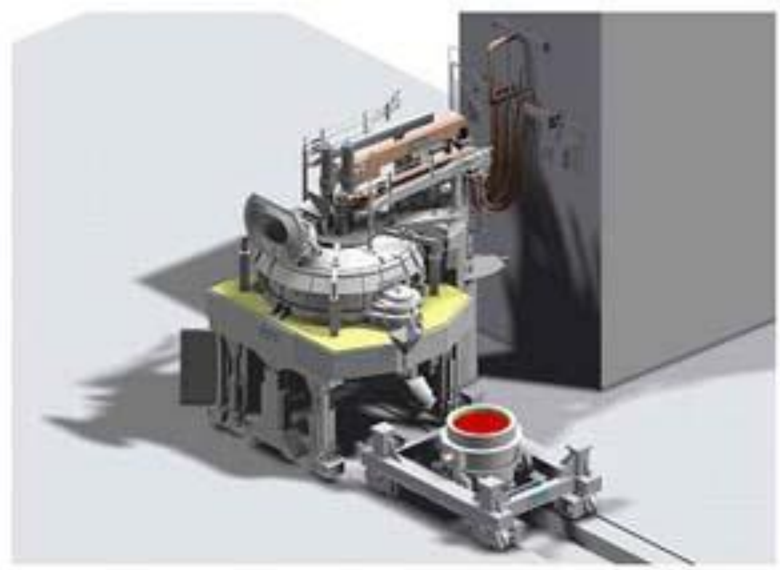

Exhibit 1 depicts Siemens EAF designed to melt direct reduced iron (150 tons per heat).

Picture Credit: http://www.siemens.com/press/en/pressrelease/?press=/en/pressrelease/2012/industry/metals-technologies/imt201201071.htm&content[]=IMT&content[]=PDMT

There is a specialty variation of the EAF known as the vacuum arc remelting (VAR) furnace for air-sensitive reactive metals such as titanium (Ti) and nickel (Ni)-based superalloys. For VAR, scrap is combined with virgin metal (such as Ti sponge) and compacted into a round electrode subsequently mounted through the furnace roof. Sometimes, the cylindrical electrode is cast via a preliminary vacuum induction melt (VIM) stage. Fed with DC power at high amperage levels, this electrode strikes an electric arc with the bottom of the vacuum furnace (actually a water-cooled copper crucible) or the melt pool at the bottom of the crucible, and sacrifices itself by melting away. For critical rotating-grade Ti parts in jet engines, the industry standard is now triple-melt VAR ingots, to remove harmful constituents such as hard inclusions and other undesirable materials.

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2. HIGHLY EFFICIENT 5-AXIS MACHINING

The five axis machining of the geometrically complex parts used in aerospace and medical applications often involves using a machining center that is limited to single or dual pallet loads. Makino's Tech Center in Mason, Ohio has recently introduced its a51nx-5XU 5-Axis horizontal machining center or HMC to integrate all phases of five-axis machining of complex parts. This will permit manufacturers to achieve higher levels of efficiency.

Makino is a leading developer of computer numerically controlled machining centers, horizontal machining centers, vertical machining centers, and five-axis machining centers are all included in the multinational firm's product portfolio.

Engineers at Makino were determined to liberate part manufacturers from the single pallet load that the standard, small 5-axis horizontal machining solutions are limited to. They achieved this by providing the a51nx-5XU with a horizontal orientation, integral cast fifth-axis table and integrated workpiece automation. This combination of novel features helps to eliminate recutting of chips and stack-up errors and other challenges of 5-axis part loading.

The designers borrowed the structure of the new machining center's linear X, Y, and Z axes from Makino's a51nx horizontal machining center. This integrates a rigid bed casting with a three-point leveling system to form a robust foundation for the system. The a51nx-5XU is built with a tiered-column design to redirect machining forces while resisting deflection. High-performance linear guides augment the dynamic stiffness and management of vibration that this design provides.

A key market for the a51nx-5XU is in companies that are adding aftermarket 5-axis rotary tables to their legacy 4-axis machining centers. These retrofit solutions often do not provide the required rigidity of 5-axis machining and interfere with managing cables. The new Makino center's single-piece casting design and integrated B and C axes twin direct-drive motors gives needed rigidity, while cables are concealed to the roofline of the machining center's splashguard. This allows operators and maintenance personnel to access and manage cables outside the machining area. The rotary table removes the stack-up errors, lack of rigidity, and cable managing troubles that plague many table-on-table machining designs.

The large direct-drive B- and C-axis motors rapidly traverse at 75 and 150 revolutions per minute, reducing non-cutting times and raising productivity. The motor stators and bearing perimeters are jacket cooled to prevent thermal deformation. A BT-style, 50-taper Big Plus interface and clamping mechanism aids the C-axis by locating and clamping the workpiece inside the envelope of the 5-axis machine.

The Makino design team replaced the traditional horizontal pallet changer found in most horizontal machining centers with an innovative work-pallet magazine, or WPM, that automates workpiece changeovers for unattended operation. The new magazine also makes it easier for a51nx-5XU operators to load and unload workpieces.

The a51nx-5XU WPM holds 22 different work pieces up to 300 millimeters in diameter and 300 mm tall, with an optional magazine capable of storing up to 58 work pieces up to 200 mm in diameter. Operators mount the parts directly to the 540-taper, dual-contact holders, which are then stored in the WPM matrix to conduct continuous and unattended production.

A work-setting station within the WPM system is dedicated to loading and setup, while a work data management panel close at hand enables operators to process each pallet's data and devise optimal work schedules. Operators can set and change priorities for each pallet to reflect engineering changes or to fulfill an important one-off order. Makino provides its MAS-A5 control system when more sophisticated scheduling control and machine networking are needed.

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3. EVOLUTION OF NUMERICAL CONTROL TECHNOLOGY

The original punched-card numerical control (NC) technology appeared in experimental automated metalworking machine tools in the early 1940s. NC replaced many manual-controlled and cam-controlled machine tools over time. The potential benefits were better consistency and repeatability from part to part. Motorized actuators (servo and selsyn controls) moved machine controls from point to point along a map of points, according to commands on the punched card. This sharply reduced human error, but still had technical challenges--the cuts were jagged for lack of a feedback loop. MIT in the early 1950s found a solution, added feedback, and changed to a 7-track punched tape, which controlled the X, Y, and Z cutting axes of a milling machine. Demonstrations in 1952 and beyond showed extreme accuracy, better than any manual operator. Unfortunately the system was way too complex, loaded with excess parts (such as 250 vacuum tubes and 175 relays) and accordingly was too costly.

A number of machine tool companies, such as Giddings & Lewis, developed the NC technology further. However, industry uptake of this unfamiliar and untrusted means of machine control was very slow.. Paper tape was replaced with magnetic tape on the factory floor, but the original encoding remained on paper tape.

A major upgrade to numerical control was implemented with the advent of analog and then digital computer numerical control (thus, CNC) in lieu of tape NC. A consortium of industry members, USAF, and MIT collaborated on a common computer programming language (APT), and the result was announced publicly in February 1959 with a CNC 3D-machined aluminum ash tray. Speed and precision were enhanced with CNC as well as the ability to perform more complex machining tasks. As solid state digital computers proliferated in the 1960s, CNC programming costs declined. The advent of more economical digital minicomputers further accelerated the appeal of CNC. New and better programming languages were launched, such as G-code

US CNC suppliers concentrated on top-end applications, so they forfeited lower cost machines to German and Japanese suppliers. As a result, US-supplier market share declined until the late 1980s. Eventually, a US-born innovation appeared, programming CNC with personal computers, now fairly common, with special software tools. A recent advance in CNC involves logic commands, also known as parametric programming, that involves direct commands coupled with a BASIC-like computer control language. Also, introduced was direct numerical control (DNC) which networks machine tools with a controller, via cable or wireless links to a central CNC computer that has plenty of memory and computing power. Dedicated mini computers at each machine tool may or may not have the memory and power to do the job.

The latest concept involves application of Web software development and smart phone app software development into the world of CNC and DNC. That is, an app marketplace can be created, useful to many sorts of factory automation uses, including CNC and DNC. MTConnect is a manufacturing industry standard facilitating this trend It is also standard modern practice to integrate computer-aided design (CAD) and computer-aided manufacturing (CAM) programs with CNC.

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4. PATENT ANALYSIS OF CONTINUOUS CASTING

Continuous casting is the process in which molten metal is solidified into semi-finished billet, bloom or slab for subsequent rolling in the finishing mills. Before the advent of continuous casting, the ingots were formed by pouring steel into stationary molds. Since then, continuous casting has developed over time to achieve improved yield, quality, productivity, and cost efficiency. Continuous casting enables the production of metal sections at lower cost and with better quality due to the lower cost of the standardization production of the product and also it provides greater control over the process through automation.

A recent patent in continuous casting, US8662145 B2, is assigned to Novelis Inc. and pertains to the method and apparatus for continuous casting a metal slab.

Recent trends suggest that companies are focusing on using continuous casting for various purposes. For example, Hyundai Steel Company's patent on a new method for continuous casting of a beam blank and Jfe Steel Corporation's patent on a new method for continuous casting of steel and method for manufacturing steel sheet highlight this trend.

A number of patents on improving the efficiency of the continuous casting process have been filed in the last five years. RTI International Metals, Inc. has filed a patent in which the continuous casting furnace is configured for casting ingots that include titanium alloy ingots. The Board of Trustees of the University of Illinois has filed a patent pertaining to a new cooling control system for continuous casting of metals.

Title	Publication Date/Publication Number	Assignee	Inventor	Abstract
Continuous casting furnace for long ingot casting	Mar 25, 2014 / US8678074 B1	Rti International Metals, Inc.	Michael P. Jacques, Kuang-O Yu	A continuous casting furnace is configured for efficiently continuously casting ingots, including titanium alloy ingots. The furnace is configured with an internal cutter for cutting an ingot within the furnace interior chamber. The furnace typically includes a first interior chamber in which a continuous casting mold is disposed and a withdrawal chamber which is separable from the first interior chamber to facilitate withdrawal of finished ingots therefrom while casting continues within the first chamber.
Cooling control system for continuous casting of metal	Feb 18, 2014 / US8651168 B2	Board Of Trustees Of The University Of Illinois	Brian G. Thomas, Joseph Bentsman, Kai Zheng	Maintaining the shell surface temperature profile under transient conditions by spray water cooling in continuous casting of steel is often desired to reduce occurrence of surface cracks. For this purpose, a real-time spray-cooling control system is provided that includes one or more of: a virtual sensor for accurate estimation/prediction of shell surface temperature, control algorithm and data checking subroutines for robust temperature control, server and client programs for communicating between these software components and the caster, and a real-time monitor to display the predicted shell surface temperature profiles, water flow rates, and operating data, among other things.
Method of and apparatus for casting metal slab	Mar 4, 2014 / US8662145 B2	Novelis Inc.	Kevin Michael Gatenby, Edward Stanley Luce	Embodiments of the invention relate to a method and apparatus for continuously casting a metal slab. The method involves continuously introducing molten metal into an inlet of a casting cavity defined between advancing casting surfaces, cooling the metal in the cavity to form a metal slab, and discharging the slab from the cavity through an outlet. The casting surfaces have an ability to remove heat from the metal but this ability is reduced, thus reducing heat flux, for at least one of the casting surfaces in a region of the cavity spaced from both the inlet and the outlet and extending transversely to the casting direction. This reduced ability to remove heat is relative to such ability of the casting surface in immediately adjacent upstream and downstream regions of the cavity. The apparatus may be a twin belt caster or other form of continuous caster modified to perform the method.
Method and apparatus for continuous casting	Sep 3, 2013 / US8522858 B2	Sms Siemag Aktiengesellschaft	Uwe Plociennik, Jens Kempken, Peter Jonen, Ingo Schuster, Tilmann Böcher	A method for continuous casting from molten metal, where metal flows vertically downward from a mold and metal strip is then guided vertically downward along a vertical strand guide, cooling as it moves. The strip is deflected from the vertical direction to the horizontal direction. In the terminal area of the deflection of the strip into the horizontal direction or after the deflection into the horizontal direction, a mechanical deformation of the strip is carried out. The strip is cooled at a heat-transfer coefficient of 3,000 to 10,000 W/(m² K) in a first section downstream of the mold and upstream of mechanical deformation of the strip. In a second section, downstream of the cooling, the strip surface is heated to a temperature above Ac3 or Ar3 by heat equalization in the strip. The mechanical deformation is subsequently carried out in a third section.
Method of continuous casting of beam blank	Nov 6, 2012 / US8302666 B2	Hyundai Steel Company	Seangjun HWANG, Jeongjae KIM, Pankeun KIM	A method of continuous casting a beam blank adapted for impact absorption is disclosed. The method includes: introducing molten steel into a continuous casting mold from a tundish through an immersion nozzle to perform non-oxidation casting, wherein the immersion nozzle is disposed at one side of the continuous casting mold forming both side flanges of a beam blank, and the molten steel is introduced into the continuous casting mold through the immersion nozzle. The method is advantageous in that it is possible to produce steel adapted for low-temperature impact absorption, and productivity is improved due to the increase of the number of consecutive heats of continuous casting.
Continuous casting device	Apr 10, 2012 / US8151867 B2	Abb Ab	Boo Eriksson, Jan-Erik Eriksson, Christopher Curran	A continuous casting device, including a mould, an electromagnetic device arranged outside the mould and arranged to provide an electromagnetic field acting on a melt in the mould, the electromagnetic device being supplied with electric current includes a base frequency and harmonics, and thereby providing a first electromagnetic field based on the base frequency and a second electromagnetic field based on the harmonics, and an inductive sensor, arranged at the mould for the purpose of sensing the position of a meniscus of the melt, and operating at frequencies corresponding to the harmonics. The continuous casting device includes at least one screen between the electromagnetic device and the sensor, and the screen is arranged so as to prevent the second electromagnetic field from disturbing the operation of the sensor but to permit the first electromagnetic field to act on the melt in the region of the meniscus.
Continuous casting method for steel and method for manufacturing steel sheet	Dec 3, 2013 / US8596334 B2	Jfe Steel Corporation	Yuji Miki, Takeshi Murai, Hiroyuki Ohno	In a method for continuously casting an extremely low carbon steel using a continuous casting machine, by adjusting the chemical components of extremely low carbon steel within a specified range by taking into account an interface tension gradient in a concentration boundary layer on a front surface of a solidified shell, and also by optimizing intensities of the DC magnetic fields applied to the upper magnetic poles and the lower magnetic poles respectively corresponding to a slab width of a slab to be casted and a casting speed, it is possible to acquire the slab having high quality not only with the small number of defects caused by the entrainment of bubbles, non-metallic inclusion and a mold flux into the molten steel.

Title	Publication Date/Publication Number	Assignee	Inventor	Abstract
Strand guiding apparatus for continuous casting equipment	Mar 5, 2013 / US8387681 B2	Kobe Steel, Ltd.	Hiroshi Kawaguchi, Fumiki Asano, Kazunori Okada	A strand guiding apparatus includes a plurality of pairs of rollers arranged along a moving direction of a strand, a plurality of drive motors for generating driving forces to drive the pairs of rollers, a plurality of worm reducers for transmitting the driving forces of the drive motors to the pairs of rollers while reducing the rotational speed of the drive motors, each worm reducer having a worm extending in a direction orthogonal to an axis of the corresponding roller, and operable to transmit a load occurring at the roller to the corresponding drive motor, and a control unit for controlling the respective rotational speeds of the rollers and/or the respective driving forces of the drive motors based on the load to the drive motors. The reliable control for drive rollers can be attained to have a proper rotational speed without causing a reduction in surface quality and chatter in a strand guiding apparatus for continuous casting equipment using worm reducers.
Apparatus for starting the casting of a continuous casting system	Sep 18, 2012 / US8267150 B2	Sms Concast Ag	Philip Eichenberger, Thomas Meier	An apparatus for starting the casting of a continuous casting system has a mold (2) and a strand guide (**10; 10'**) comprising drive and guide rollers (**11, 12; 11', 12'**). Moreover, a dummy bar (**22**) that can be introduced into the mold (2) by the strand guide (**10; 10'**) and be withdrawn from said mold is provided. A safety device (**20; 20'**) for the dummy bar (**22**) has an element (**25**) that can be engaged, with form fit, with the dummy bar (**22**) and limiting the speed of the cold bar (**22**). It is thus guaranteed that a predetermined maximum strand speed can not be exceeded and that the dummy bar does not slide through.
Continuous casting of lead alloy strip for heavy duty battery electrodes	Apr 22, 2014 / US8701745 B2	Mitek Holdings, Inc.	Jeffrey A. Rossi, Theodore J. Seymour	A method of continuously casting a lead alloy strip includes continuously supplying molten lead alloy to a tundish having a lip insert and containing a pool of molten lead alloy. The molten lead alloy is continuously supplied to the pool from a bath maintained at a temperature in the range of 575° to 750° F. The surface level of the molten alloy in the lip insert is controlled to produce a strip of desired thickness. The temperature of the lead alloy in the lip insert is controlled in a range of about 640° to 750° F. An abraded casting surface is moved upwardly through the pool for depositing the lead alloy thereon. The abraded casting surface is cooled to a temperature in the range of about 100° to 210° F. to solidify a strip of lead alloy, and the lead alloy strip is stripped from the abraded casting surface.

Exhibit 2 depicts patents related to continuous casting.

Picture Credit:Frost & SUllivan

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