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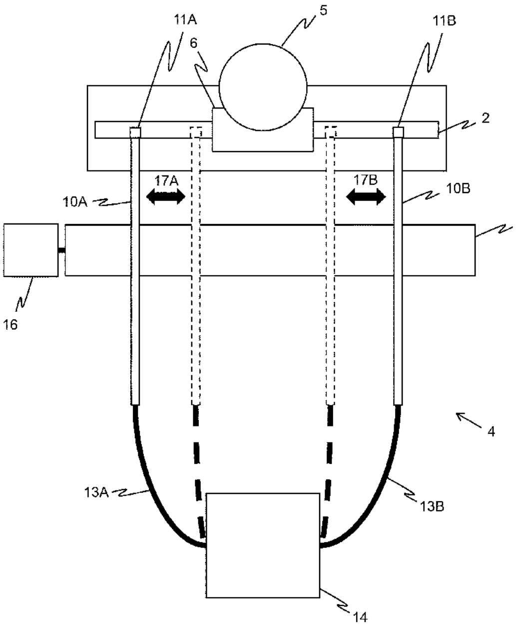

Fig. 4

(57) **Abstract:** A flux delivery apparatus for delivering flux to a mold during a continuous casting process comprises: one or more flux outlets for delivering flux to the mold; one or more actuators operable to actuate movement of the one or more flux outlets relative to the mold; and a controller configured to operate the one or more actuators to move the one or more flux outlets relative to the mold.

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FLUX DELIVERY FOR CONTINUOUS CASTING

Field

The present disclosure concerns flux delivery apparatus for delivering flux to a mold during a continuous casting process, flux delivery support apparatus for a continuous casting process, continuous casting apparatus comprising flux delivery apparatus or flux delivery support apparatus, and methods of delivering flux to a mold during a continuous casting process.

Background

It is customary to apply a flux (otherwise known as mold flux, casting flux, mold powder or casting powder), which may be a powder or granular material, onto the top of a strand during continuous casting of a molten metal such as steel. The flux turns into slag when sufficiently heated by the molten metal. Fluxes are engineered synthetic slags formed by compounds containing oxides, minerals and carbonaceous materials which are selected to provide desired characteristics. For example, the flux may include silica, bauxite, calcium silicate/wollastonite, feldspar, soda ash, fluorspar, lithium carbonate, and the like.

At the zone of contact with the liquid metal, the flux serves to prevent reoxidation and avoid heat loss so as to prevent premature solidification of the liquid metal. The flux also absorbs non-metallic inclusions at the liquid slag-metal interface, thereby producing cleaner metal. Further, at the zone of contact with the solidified metal, the flux provides lubrication between the solidified metal shell and the mold. The flux also plays an important role in controlling heat transfer, particularly in a horizontal direction. These functions have a direct impact on the quality and operational stability of the cast metal. For example, inadequate lubrication of the flux can cause loss of containment of the liquid metal due to high friction and shell tearing. Insufficient heat removal will result in a thin shell that cannot withstand the ferrostatic pressure and lose containment. Excessive heat removal can cause cracks to form on the strand surface. It is particularly important that a homogenous layer of flux is formed on top of the strand during casting.

Liquid slag is consumed during the casting process. It is therefore necessary to add flux to the mold on an ongoing basis as casting proceeds. Flux in the mold may be replenished intermittently or continuously. Flux is typically pumped into a continuous casting mold by way of one or more flexible hoses located at fixed positions along an axis of the mold.

Summary

According to a first aspect, there is provided a flux delivery apparatus for delivering flux to a mold during a continuous casting process. The flux delivery apparatus comprises: one or more flux outlets for delivering flux to the mold; one or more actuators operable to actuate movement of the one or more flux outlets (i.e. relative to the mold); and a controller configured to operate the one or more actuators to move the one or more flux outlets (i.e. relative to the mold).

By moving the one or more flux outlets relative to the mold, the location at which flux is delivered to the mold can be varied. Accordingly, flux can be distributed evenly across the mold or a region thereof, for example by (e.g. continuously) delivering flux to the mold via the one or more flux outlets while operating the one or more actuators to move the one or more flux outlets relative to the mold. Additionally or alternatively, regions of the mold requiring more flux (for example, because the thickness of a layer of flux in said regions is lower than in other regions) can be targeted for flux delivery, for example by operating the one or more actuators to move the one or more flux outlets to the regions requiring more flux and delivering flux to the mold in the said regions via the one or more flux outlets.

Moving the one or more flux outlets to achieve an even distribution of flux within the mold provides several benefits in comparison to continuous casting apparatus in which flux is delivered to a mold at one or more fixed positions. For example, delivering flux to the mold at one or more fixed positions can cause: formation of a low unmelted flux layer, which results in low levels of insulation, leading to low slag generation, large meniscus hook formation, freezing of metal in the mold and contact between the metal and the atmosphere; large amounts of flux building up at discrete flux discharge points, leading to hip formation (i.e., flux powder layer depth fluctuations within the mold), slag entrapment, meniscus deformation, metal carbonization and uneven fusion; and use of starve and feed methods, leading to variations in insulation and consequently inconsistent slag generation, varying slag chemistry due to inclusion absorption, rope formation and uneven meniscus formation. In turn, this can lead to problems such as: loss of lubrication leading to breakouts; quality problems associated with deep oscillation marks; formation of floaters; re-oxidation of the metal; entrapment breakout; slowdowns due to hip formation; sticker breakout due to thin slag depths; and variation in heat removal and consumption due to varying slag chemistry. However, the inventors have found that the occurrence of such problems can be reduced by varying the locations at which flux is delivered to the mold, thereby achieving a more even distribution of flux within the mold.

The flux delivery apparatus may comprise a single (i.e. only one) flux outlet for delivering flux to the mold. The one or more actuators may be operable to actuate movement of the single flux outlet relative to the mold. The controller may be configured to operate the one or more actuators to move the single flux outlet relative to the mold.

Alternatively, the flux delivery apparatus may comprise two or more flux outlets for delivering flux to the mold. For example, the flux delivery apparatus may comprise at least first and second flux outlets for delivering flux to the mold. The one or more actuators may be operable to actuate movement of the two or more (e.g. at least first and second) flux outlets relative to the mold. The controller may be configured to operate the one or more actuators to move the two or more (e.g. at least first and second) flux outlets relative to the mold.

In embodiments in which the flux delivery apparatus comprises two or more (e.g. at least first and second) flux outlets, the controller may be configured to operate the one or more actuators to move the two or more (e.g. at least first and second) flux outlets at the same time (i.e. concurrently) in the same direction or in opposing directions relative to the mold.

The controller may be configured to operate the one or more actuators to move the one or more flux outlets periodically relative to the mold. For example, the controller may be configured to operate the one or more actuators to move the one or more flux outlets back and forth relative to the mold, i.e. the controller may be configured to operate the one or more actuators to cause the one or more flux outlets to reciprocate back and forth relative to the mold.

It may be that the one or more actuators are operable to actuate movement of the one or more flux outlets along or parallel to a first axis. It may be that the one or more actuators are further operable to actuate movement of the one or more flux outlets along or parallel to a second axis angled with respect to, for example orthogonal to, the first axis. It may be that the one or more actuators are further operable to actuate movement of the one or more flux outlets along or parallel to a third axis angled with respect to, for example orthogonal to, both the first axis and the second axis.

It may be that movement of the one or more flux outlets (as driven by actuation of the one or more actuators) is restricted (for example, by one or more guides) to directions along or parallel to the first axis. It may be that movement of the one or more flux outlets (as driven by actuation of the one or more actuators) is restricted (for example, by one or more guides) to directions in or parallel to a plane containing the first and second axes. Alternatively, it may be that the direction in which the one or more flux outlets may move is unrestricted.

It may be that the one or more actuators are operable to actuate movement of the one or more flux outlets in a single substantially horizontal direction. It may be that the one or more actuators are operable to actuate movement of the one or more flux outlets in a substantially horizontal plane (for example, along first and second directions, angled, e.g. orthogonal, with respect to one another). Additionally or alternatively to movement in the single substantially horizontal direction or movement in the substantially horizontal plane, it may be that the one or more actuators are operable to actuate movement of the one or more flux outlets in a substantially vertical direction. It may be that the one or more actuators are operable to actuate movement of the one or more flux outlets in three dimensions.

The flux delivery apparatus may comprise one single (i.e. only one) actuator operable to actuate movement of the one or more flux outlets relative to the mold. Alternatively, the flux delivery apparatus may comprise two or more actuators operable to actuate movement of the one or more flux outlets relative to the mold. For example, it may be that the flux delivery apparatus comprises at least one actuator for each flux outlet. Alternatively, it may be that the flux delivery apparatus comprises at least one actuator for each direction in which the one or more flux outlets are movable.

The one or more actuators may comprise one or more motors and one or more actuating elements. The one or more motors may be operably coupled to the one or more flux outlets by way of the one or more actuating elements. Actuating the one or more actuators may comprise the one or more motors moving the one or more actuating elements and thereby moving the corresponding one or more flux outlets.

The flux delivery apparatus may comprise an encoder for monitoring the positions of the one or more actuators (e.g. the one or more actuating elements). For example, the or each motor may be a servomotor which includes an encoder. Additionally or alternatively, the flux delivery apparatus may comprise a servomechanism for use in controlling the positions of the one or more actuators. For example, the servomechanism may form part of the controller.

The one or more actuators may, for example, be mechanical (including electromechanical) actuators, hydraulic actuators or pneumatic actuators. Mechanical (including electromechanical) actuators may, for example, include screw actuators (e.g. leadscrews, screw jacks, ball screws and roller screws) and/or wheel and axle actuators (e.g. rack and pinion, chain drive, belt drive, rigid chain and rigid belt actuators).

It may be that the one or more actuators comprise one or more linear actuators operable to actuate linear movement of the one or more flux outlets along or parallel to the first axis, the second axis and/or the third axis. Examples of linear actuators include leadscrews, screw jacks, ball screws, roller screws, rack and pinion actuators, chain drives, belt drives, rigid chain actuators and rigid belt actuators. Accordingly, it may be that the one or more linear actuators comprise one or more leadscrews for actuating linear movement of the one or more flux outlets along or parallel to the first axis, the second axis and/or the third axis.

It may be that flux delivery apparatus comprises two or more leadscrews for actuating movement of at least first and second flux outlets. For example, it may be that the flux delivery apparatus comprises first and second leadscrews configured to actuate movement of corresponding first and second flux outlets along the same axis. The flux delivery apparatus may comprise a motor for applying torque to the first leadscrew to thereby cause the first leadscrew to rotate in a first sense. The first and second leadscrews may be coupled to one another by way of a gear mechanism for transferring torque from the first leadscrew to the second leadscrew. The first and second leadscrews and the gear mechanism may be configured such that the second leadscrew rotates in a second sense opposite the first sense when the first leadscrew rotates in the first sense. Alternatively, the first and second leadscrews and the gear mechanism may be configured such that the first and second leadscrews rotate in the same sense when the motor applies a torque to the first leadscrew. The first and second flux outlets may be coupled to the first and second leadscrews. For example, the first and second flux outlets may be coupled to the first and second leadscrews by first and second carriages mounted on the first and second leadscrews.

The flux delivery apparatus may comprise a base, the one or more actuators may be operable to actuate movement of the one or more flux outlets relative to the base, and the controller may be configured to operate the one or more actuators to move the one or more flux outlets relative to the base. It will be appreciated that movement of the one or more flux outlets relative to the base corresponds to movement of the one or more flux outlets relative to the mold when the base is positioned adjacent the mold.

The flux delivery apparatus may comprise flux feeding apparatus for feeding flux to the one or more flux outlets from a flux storage. For example, the flux delivery apparatus may comprise one or more flux feeding tubes for feeding flux to the one or more flux outlets from a flux storage. It may be that the one or more flux outlets are located at or correspond to (e.g. are) one or more respective open ends of the one or more flux feeding tubes (i.e. each flux outlet is located at or corresponds to (e.g. is) a respective one of the one or more open ends of the one or more flux feeding tubes). The one or more flux outlets may be one or more flux distributors located at the one or more respective open ends of the one or more flux feeding tubes. The flux delivery apparatus may comprise the flux storage. Additionally or alternatively, the flux delivery apparatus (e.g. the flux feeding apparatus) may comprise a pump for pumping flux from the flux storage, through the one or more flux feeding tubes, to the one or more flux outlets. The flux storage may be a flux container, for example a flux silo or a flux hopper.

The one or more flux feeding tubes may comprise (e.g. be) one or more rigid flux feeding tubes, for example formed from metal. The one or more flux feeding tubes may comprise (e.g. be) one or more flexible flux feeding tubes (e.g. one or more flexible flux feeding hoses), for example formed from rubber. It may be that each of the one or more flux feeding tubes comprises a rigid flux feeding tube (for example, formed from metal) and a flexible flux feeding tube (e.g. a flexible flux feeding hose) (for example, formed from rubber) connected to one another to permit flow of flux therebetween. Each rigid flux feeding tube may be connected to each flexible flux feeding tube (e.g. each flexible flux feeding hose) by a connector, such as a quick-release connector. Each flux outlet may be located at or correspond to (e.g. be) a respective one of one or more open ends of the one or more rigid flux feeding tubes. The one or more flux outlets may be one or more flux distributors located at the one or more respective open ends of the one or more rigid flux feeding tubes. Each flexible flux feeding tube (e.g. each flexible flux feeding hose) may be connected to the flux storage for receiving a flow of flux.

It may be that the one or more actuators are operable to actuate movement of the one or more flux feeding tubes (e.g. the one or more rigid flux feeding tubes), thereby actuating movement of the one or more flux outlets. For example, it may be that each of the one or more flux feeding tubes (e.g. the one or more rigid flux feeding tubes) is coupled to the one or more actuators. For example, in embodiments comprising one or more leadscrews for actuating movement of the one or more flux outlets, the one or more flux feeding tubes (e.g. the one or more rigid flux feeding tubes) may be coupled to the one or more leadscrews by one or more carriages mounted on the one or more leadscrews.

It may be that the controller is configured to set one or more operating parameters for the one or more actuators. The one or more operating parameters for the one or more actuators may include a direction of travel (e.g. along or parallel to one or more of the first, second and/or third axes), a travel distance and/or a speed of travel for the one or more actuators and/or the one or more flux outlets (e.g. the one or more flux feeding tubes) moved by the one or more actuators.

The travel distance for each actuator and/or flux outlet (e.g. flux feeding tube) may be no less than about 100 mm, for example, no less than about 250 mm, or no less than about 500 mm. The travel distance for each actuator and/or flux outlet (e.g. flux feeding tube) may be no more than about 10000 mm, for example, no more than about 5000 mm, or no more than about 2500 mm. The travel distance for each actuator and/or flux outlet (e.g. flux feeding tube) may be from about 100 mm to about 10000 mm, or from about

250 mm to about 5000 mm, or from about 500 mm to about 2500 mm, for example about 1000 mm.

The speed of travel for each actuator and/or flux outlet (e.g. flux feeding tube) may be no less than about 25 mm/s, for example, no less than about 50 mm/s, or no less than about 75 mm/s, or no less than about 100 mm/s. The speed of travel for each actuator and/or flux outlet (e.g. flux feeding tube) may be no more than about 500 mm/s, for example, no more than about 400 mm/s, or no more than about 300 mm/s. The speed of travel for each actuator and/or flux outlet (e.g. flux feeding tube) may be from about 25 mm/s to about 500 mm/s, or from about 50 mm/s to about 400 mm/s, or from about 75 mm/s to about 300 mm/s, or from about 100 mm/s to about 300 mm/s, for example about 200 mm/s.

It may be that the controller is configured to set the one or more operating parameters for the one or more actuators based at least in part on (i.e. taking into account) one or more control inputs. The one or more control inputs may include a mold dimension such as a mold width.

The flux delivery apparatus may comprise a user interface, such as a human-machine interface, for supplying the controller with one or more user inputs. The one or more user inputs may be the one or more control inputs. The controller may comprise the user interface. Alternatively, the user interface may be provided on a remote device.

The controller may comprise a processor (e.g. a microprocessor). It will be appreciated that any references herein to the controller being configured to carry out a particular function encompass the processor (e.g. microprocessor) being configured (e.g. programmed) to carry out said function. The processor (e.g. microprocessor) may be in electronic communication with a memory storing instructions (e.g. a computer program in the form of computer executable program code) configured to cause the processor (e.g. microprocessor) to carry out said function.

The controller may be a programmable logic controller (PLC). The controller may be part of a supervisory control and data acquisition (SCADA) system, which may form part of the flux delivery apparatus.

The flux delivery apparatus may comprise a flux feeding controller configured to set one or more operating parameters for the flux feeding apparatus. For example, the flux feeding controller may be configured to control operation of the pump, for pumping flux from the flux storage to the one or more flux outlets. Additionally or alternatively, the flux feeding controller may be configured to control operation of one or more valves for regulating the flow of flux from the flux storage to the one or more flux outlets. The one or more operating parameters may include an amount of flux fed to the one or more flux outlets, a rate at which flux is fed to the one or more flux outlets and/or a flux composition (e.g. a flux type).

The flux feeding controller may be configured to set the one or more operating parameters for the flux feeding apparatus based at least in part on (i.e. taking into account) one or more casting process inputs indicative of one or more casting process parameters. The one or more casting process inputs may be one or more sensor inputs received from one or more sensors configured to measure the one or more casting process parameters. The flux delivery apparatus may comprise the one or more sensors for measuring the one or more casting process parameters. The one or more sensors may supply the flux feeding controller with the one or more sensor inputs indicative of the measured casting process parameters. The one or more casting process parameters may include a grade of metal being cast, a casting speed, a flux consumption rate, a heat transfer rate, a flux type, a slag temperature, a metal temperature, a metal flow condition, a flux thickness, a slag thickness, a mold width, a section size and/or a taper. The one or more sensors may include one or more temperature sensors, laser measurement devices, ultrasonic measurement devices, infrared sensors, thermal imaging sensors and/or microwave sensors. The one or more sensors may be located at or adjacent the mold, at the one or more flux outlets, or on the one or more flux feeding tubes.

The flux feeding controller may comprise a processor (e.g. a microprocessor). It will be appreciated that any references herein to the flux feeding controller being configured to carry out a particular function encompass the processor (e.g. microprocessor) being configured (e.g. programmed) to carry out said function. The processor (e.g. microprocessor) may be in electronic communication with a memory storing instructions (e.g. a computer program in the form of computer executable program code) configured to cause the processor (e.g. microprocessor) to carry out said function.

The flux feeding controller may be a programmable logic controller (PLC). The flux feeding controller may be part of a supervisory control and data acquisition (SCADA) system, which may form part of the flux delivery apparatus.

The controller and the flux feeding controller may form part of the same control module. The controller and the flux feeding controller may form part of the same SCADA system. The controller may be the flux feeding controller, i.e. the flux delivery apparatus may comprise a (i.e. single) controller configured: (a) to operate the one or more actuators to move the one or more flux outlets relative to the mold; and (b) to set the one or more operating parameters for the flux feeding apparatus.

The flux delivery apparatus may further comprise a temperature regulation apparatus for regulating a temperature of the one or more actuators and/or the controller and/or the flux feeding controller. The temperature regulation apparatus may be a cooling apparatus for cooling the one or more actuators and/or the controller and/or the flux feeding controller. The cooling apparatus may comprise an air mover for generating an air flow around the one or more actuators and/or the controller and/or the flux feeding controller. The flux delivery apparatus may comprise a temperature sensor for measuring a temperature of the one or more actuators and/or the controller and/or the flux feeding controller. The temperature regulation apparatus (e.g. the cooling apparatus) may be configured to regulate the temperature of (e.g. cool) the one or more actuators and/or the controller and/or the flux feeding controller based at least in part on (i.e. taking into account) an input (i.e. feedback) from the temperature sensor.

According to a second aspect, there is provided a flux delivery support apparatus for a continuous casting process, the flux delivery support apparatus comprising: one or more supports for supporting one or more flux outlets and/or one or more flux feeding tubes for delivering flux to a mold; one or more actuators operable to actuate movement of the one or more supports (i.e. relative to the mold); and a controller configured to operate the one or more actuators to move the one or more supports (i.e. relative to the mold).

Each of the one or more supports may comprise attachment means (e.g. a connector) for attaching a corresponding one of the one or more flux outlets and/or one or more flux feeding tubes to the said support. For example, each of the one or more supports may comprise a bracket or clamp for attaching a corresponding one of the one or more flux outlets and/or one or more flux feeding tubes to the said support. By moving the one or more supports, when one or more flux outlets and/or one or more flux feeding tubes are attached thereto, the flux delivery support apparatus is able to move the one or more flux outlets and/or the one or more flux feeding tubes relative to the mold.

The flux delivery support apparatus may comprise a base, the one or more actuators may be operable to actuate movement of the one or more supports relative to the base, and the controller may be configured to operate the one or more actuators to move the one or more supports relative to the base. It will be appreciated that movement of the one or more supports relative to the base corresponds to movement of the one or more supports relative to the mold when the base is positioned adjacent the mold.

The flux delivery support apparatus and any of its component parts may have any of the features, *mutatis mutandis*, described hereinabove in relation to the first aspect.

For example, the flux delivery support apparatus may comprise at least first and second supports for supporting at least first and second flux outlets and/or flux feeding tubes for delivering flux to the mold. The one or more actuators may be operable to actuate movement of the first and second supports relative to the mold. The controller may be configured to operate the one or more actuators to move the first and second supports relative to the mold, for example in opposing directions.

According to a third aspect, there is provided a continuous casting apparatus comprising the flux delivery apparatus according to the first aspect or the flux delivery support apparatus according to the second aspect. The continuous casting apparatus may comprise a mold. The flux delivery apparatus or the flux delivery support may be configured (e.g. arranged) for delivering flux to the mold. The continuous casting apparatus may further comprise molten metal delivery apparatus for delivering molten metal to the mold. The molten metal delivery apparatus may comprise a tundish for delivering molten metal to the mold. In addition, the molten metal delivery apparatus may comprise one or more ladles for delivering molten metal to the tundish.

According to a fourth aspect, there is provided a method of delivering flux to a mold during a continuous casting process. The method comprises: positioning one or more flux outlets at the mold; delivering flux into the mold through the one or more flux outlets; and moving the one or more flux outlets relative to the mold to distribute the flux within the mold.

Positioning one or more flux outlets at the mold may comprise positioning the one or more flux outlets above the mold, for example, such that flux may fall into the mold from the one or more flux outlets. The one or more flux outlets may be positioned directly above the mold, for example, such that flux may fall downwards in a substantially vertical direction from the one or more flux outlets into the mold. Additionally or alternatively, positioning one or more flux outlets at the mold may comprise positioning the one or more flux outlets adjacent (e.g. above and adjacent) the mold.

The method may comprise: positioning a single (i.e. only one) flux outlet at the mold; delivering flux into the mold through the single flux outlet; and moving the single flux outlet relative to the mold to distribute flux within the mold.

Alternatively, the method may comprise: positioning two or more flux outlets at the mold; delivering flux into the mold through the two or more flux outlets; and moving the two or more flux outlets relative to the mold to distribute the flux within the mold.

For example, the method may comprise: positioning at least first and second flux outlets at the mold; delivering flux into the mold through the at least first and second flux outlets; and moving the at least first and second flux outlets relative to the mold to distribute the flux within the mold.

In embodiments in which two or more (e.g. at least first and second) flux outlets are positioned at the mold, the method may comprise moving the two or more (e.g. at least first and second) flux outlets in the same direction or in opposing directions relative to the mold. The method may comprise moving the two or more (e.g. at least first and second) flux outlets at the same time (i.e. concurrently). The method may comprise moving the two or more (e.g. at least first and second) flux outlets at the same time (i.e. concurrently) in the same direction or in opposing directions relative to the mold.

The method may comprise moving the one or more flux outlets periodically relative to the mold. For example, the method may comprise moving the one or more flux outlets back and forth relative to the mold, i.e. the method may comprise the one or more flux outlets reciprocating back and forth relative to (e.g. along a width (i.e. major axis, when viewed from vertically above) of) the mold.

The method may comprise a controller operating one or more actuators to move (i.e. to actuate movement of) the one or more flux outlets relative to the mold.

The method may comprise the controller operating the one or more actuators to move the one or more flux outlets periodically relative to the mold. For example, the method may comprise the controller operating the one or more actuators to move the one or more flux outlets back and forth relative to the mold, i.e. the method may comprise the controller operating the one or more actuators to cause the one or more flux outlets to reciprocate back and forth relative to (e.g. along a width (i.e. major axis, when viewed from above) of) the mold.

The method may comprise moving the one or more flux outlets along or parallel to a first axis. The method may further comprise moving the one or more flux outlets along or parallel to a second axis angled with respect to, for example orthogonal to, the first axis. The method may further comprise moving the one or more flux outlets along or parallel to a third axis angled with respect to, for example orthogonal to, both the first axis and the second axis.

The method may comprise the controller operating the one or more actuators to move the one or more flux outlets along or parallel to a first axis. The method may further comprise the controller operating the one or more actuators to move the one or more flux outlets along or parallel to a second axis angled with respect to, for example orthogonal to, the first axis. The method may further comprise the controller operating the one or more actuators to move the one or more flux outlets along or parallel to a third axis angled with respect to, for example orthogonal to, both the first axis and the second axis.

It may be that movement of the one or more flux outlets (as driven by actuation of the one or more actuators) is restricted (for example, by one or more guides) to directions along or parallel to the first axis. It may be that movement of the one or more flux outlets (as driven by actuation of the one or more actuators) is restricted (for example, by one or more guides) to directions in or parallel to a plane containing the first and second axes. Alternatively, it may be that the direction in which the one or more flux outlets may be moved (i.e. by the one or more actuators) is unrestricted.

The method may comprise moving the one or more flux outlets in a single substantially horizontal direction. The method may comprise moving the one or more flux outlets in a substantially horizontal plane (for example, along first and second directions, angled, e.g. orthogonal, with respect to one another). Additionally or alternatively to movement in the single substantially horizontal direction or movement in the substantially horizontal plane, the method may comprise moving the one or more flux outlets in a substantially vertical direction.

The method may comprise the controller operating the one or more actuators to move the one or more flux outlets in a single substantially horizontal direction. The method may comprise the controller operating the one or more actuators to move the one or more flux outlets in a substantially horizontal plane (for example, along first and second directions, angled, e.g. orthogonal, with respect to one another). Additionally or alternatively to movement in the single substantially horizontal direction or movement in the substantially horizontal plane, the method may comprise the controller operating the one or more actuators to move the one or more flux outlets in a substantially vertical direction.

The method may comprise the controller operating one single (i.e. only one) actuator to move the one or more flux outlets relative to the mold. Alternatively, the method may comprise the controller operating two or more actuators to move the one or more flux outlets relative to the mold. For example, the method may comprise the controller operating at least one actuator for each flux outlet. Alternatively, the method may comprise the controller operating at least one actuator for each direction in which the one or more outlets are movable.

The one or more actuators may comprise one or more motors and one or more actuating elements. The one or more motors may be operably coupled to the one or more flux outlets by way of the one or more actuating elements. Actuating the one or more actuators may comprise the one or more motors moving the one or more actuating elements and thereby moving the corresponding one or more flux outlets.

The method may comprise an encoder monitoring positions of the one or more actuators (e.g. the one or more actuating elements). For example, the or each motor may be a servomotor which includes an encoder for monitoring the positions of the one or more actuators (e.g. the one or more actuating elements). Additionally or alternatively, the method may comprise a servomechanism controlling the positions of the one or more actuators. For example, the servomechanism may form part of the controller.

The one or more actuators may, for example, be mechanical (including electromechanical) actuators, hydraulic actuators or pneumatic actuators. Mechanical (including electromechanical) actuators may, for example, include screw actuators (e.g. leadscrews, screw jacks, ball screws and roller screws) and/or wheel and axle actuators (e.g. rack and pinion, chain drive, belt drive, rigid chain and rigid belt actuators).

It may be that the one or more actuators comprise one or more linear actuators operable to actuate linear movement of the one or more flux outlets along or parallel to the first axis, the second axis and/or the third axis. Examples of linear actuators include leadscrews, screw jacks, ball screws, roller screws, rack and pinion actuators, chain drives, belt drives, rigid chain actuators and rigid belt actuators. Accordingly, it may be that the one or more linear actuators comprise one or more leadscrews for actuating linear movement of the one or more flux outlets along or parallel to the first axis, the second axis and/or the third axis.

The method may comprise the controller operating two or more leadscrews to move at least first and second flux outlets. For example, the method may comprise the controller operating first and second leadscrews to move corresponding first and second flux outlets along the same axis. The method may comprise a motor applying torque to the first leadscrew to thereby cause the first leadscrew to rotate in a first sense (it being understood that the controller operating the two or more leadscrews comprises the controller operating the motor to apply torque to the first leadscrew). The first and second leadscrews may be coupled to one another by way of a gear mechanism for transferring torque from the first leadscrew to the second leadscrew. The first and second leadscrews and the gear mechanism may be configured such that the second leadscrew rotates in a second sense opposite the first sense when the first leadscrew rotates in the first sense. Alternatively, the first and second leadscrews and the gear mechanism may be configured such that the first and second leadscrews rotate in the same sense when the motor applies a torque to the first leadscrew. The first and second flux outlets may be coupled to the at least first and second leadscrews. For example, the first and second flux outlets may be coupled to the first and second leadscrews by first and second carriages mounted on the first and second leadscrews.

The method may comprise (e.g. the one or more actuators) moving the one or more flux outlets relative to the mold and delivering flux into the mold through the one or more flux outlets at the same time (i.e. concurrently). Alternatively, the method may comprise (e.g. the one or more actuators) moving the one or more flux outlets relative to the mold and delivering flux into the mold through the one or more flux outlets at different times (e.g. sequentially).

For example, the method may comprise: positioning the one or more flux outlets at one or more first locations at the mold; delivering flux into the mold through the one or more flux outlets at the one or more first locations; (e.g. the one or more actuators) moving the one or more flux outlets relative to the mold to position the one or more flux outlets at one or more second locations at the mold, the one or more first locations being different from the one or more first locations; and delivering flux into the mold through the one or more flux outlets at the one or more second locations. The method may comprise delivering flux into the mold through the one or more flux outlets during (e.g. the one or more actuators) moving the one or more flux outlets from the one or more first locations to the one or more second locations, i.e. thereby distributing flux within the mold between the one or more first locations and the one or more second locations. Alternatively, the method may comprise delivering flux into the mold at the one or more first locations and at the one or more second locations but not during (e.g. the one or more actuators) moving the one or more flux outlets from the one or more first locations to the one or more second locations, i.e. thereby distributing flux within the mold at the one or more first locations and at the one or more second locations but not therebetween.

The method may comprise feeding flux to the one or more flux outlets from a flux storage. For example, the method may comprise a flux feeding apparatus feeding flux to the one or more flux outlets from a flux storage. The method may comprise feeding flux to the one or more flux outlets from a flux storage by way of one or more flux feeding tubes. It may be that the one or more flux outlets are located at or correspond to (e.g. are) one or more respective open ends of the one or more flux feeding tubes (i.e. each flux outlet is at or corresponds to (e.g. is) a respective one of the one or more open ends of the one or more flux feeding tubes). The one or more flux outlets may be one or more flux distributors located at the one or more respective open ends of the one or more flux feeding tubes. The method may comprise (e.g. a pump) pumping flux from the flux storage, through the one or more flux feeding tubes, to the one or more flux outlets. The flux storage may be a flux container, for example a flux silo or a flux hopper.

The one or more flux feeding tubes may comprise (e.g. be) one or more rigid flux feeding tubes, for example formed from metal. The one or more flux feeding tubes may comprise (e.g. be) one or more flexible flux feeding tubes (e.g. one or more flexible flux feeding hoses), for example formed from rubber. It may be that each of the one or more flux feeding tubes comprises a rigid flux feeding tube (for example, formed from metal) and a flexible flux feeding tube (e.g. a flexible flux feeding hose) (for example, formed from rubber) connected to one another to permit flow of flux therebetween. Each rigid flux feeding tube may be connected to each flexible flux feeding tube (e.g. each flexible flux feeding hose) by a connector, such as a quick-release connector. Each flux outlet may correspond to (e.g. be) a respective one of one or more open ends of the one or more rigid flux feeding tubes. The one or more flux outlets may be one or more flux distributors located at the one or more respective open ends of the one or more rigid flux feeding tubes. Each flexible flux feeding tube (e.g. each flexible flux feeding hose) may be connected to the flux storage for receiving a flow of flux.

The method may comprise moving the one or more flux feeding tubes (e.g. the one or more rigid flux feeding tubes). For example, the method may comprise the controller operating the one or more actuators to move the one or more flux feeding tubes (e.g. the one or more rigid flux feeding tubes), thereby moving the one or more flux outlets. For example, it may be that each of the one or more flux feeding tubes (e.g. the one or more rigid flux feeding tubes) is coupled to the one or more actuators. For example, in embodiments comprising one or more leadscrews for actuating movement of the one or more flux outlets, the one or more flux feeding tubes (e.g. the one or more rigid flux feeding tubes) may be coupled to the one or more leadscrews by one or more carriages mounted on the one or more leadscrews.

The method may comprise the controller setting one or more operating parameters for the one or more actuators. The one or more operating parameters for the one or more actuators may include a direction of travel (e.g. along or parallel to one or more of the first, second and/or third axes), a travel distance and/or a speed of travel for the one or more actuators and/or the one or more flux outlets (e.g. the one or more flux feeding tubes) moved by the one or more actuators.

The method may comprise the controller setting the one or more operating parameters for the one or more actuators based at least in part on (i.e. taking into account) one or more control inputs. The one or more control inputs may include a mold dimension such as a mold width.

The method may comprise the controller receiving one or more user inputs. For example, the method may comprise supplying the controller with the one or more user inputs. The one or more user inputs may be supplied via a user interface, such as a human-machine interface. The one or more user inputs may be the one or more control inputs. The controller may comprise the user interface. Alternatively, the user interface may be provided on a remote device.

The controller may comprise a processor (e.g. a microprocessor). It will be appreciated that any references herein to the controller carrying out a particular function encompass the processor (e.g. microprocessor) carrying out said function. The processor (e.g. microprocessor) may be in electronic communication with a memory storing instructions (e.g. a computer program in the form of computer executable program code) configured to cause the processor (e.g. microprocessor) to carry out said function.

The controller may be a programmable logic controller (PLC). The controller may be part of a supervisory control and data acquisition (SCADA) system.

The method may comprise setting one or more operating parameters for the flux feeding apparatus. The method may comprise a flux feeding controller setting the one or more operating parameters for the flux feeding apparatus. For example, the method may comprise (e.g. the flux feeding controller) controlling operation of the pump, for pumping flux from the flux storage to the one or more flux outlets. Additionally or alternatively, the method may comprise (e.g. the flux feeding controller) controlling operation of one or more valves for regulating the flow of flux from the flux storage to the one or more flux outlets. The one or more operating parameters may include an amount of flux fed to the one or more flux outlets, a rate at which flux is fed to the one or more flux outlets and/or a flux composition (e.g. a flux type).

The method may comprise (e.g. the flux feeding controller) setting the one or more operating parameters for the flux feeding apparatus, for feeding flux to the one or more flux outlets from the flux storage, based at least in part on (i.e. taking into account) one or more casting process inputs indicative of one or more casting process parameters. The one or more casting process inputs may be one or more sensor inputs received from one or more sensors configured to measure the one or more casting process parameters. The method may comprise (e.g. the flux feeding controller) receiving the one or more sensor inputs indicative of the measured casting process parameters. The method may comprise (e.g. the one or more sensors) supplying the flux feeding controller with the one or more sensor inputs indicative of the measured casting process parameters. The one or more casting process parameters may include a grade of metal being cast, a casting speed, a flux consumption rate, a heat transfer rate, a flux type, a slag temperature, a metal temperature, a metal flow condition, a flux thickness, a slag thickness, a mold width, a section size and/or a taper. The one or more sensors may include one or more temperature sensors, laser measurement devices, ultrasonic measurement devices, infrared sensors, thermal imaging sensors and/or microwave sensors. The one or more sensors may be located at or adjacent the mold, at the one or more flux outlets, or on the one or more flux feeding tubes.

The flux feeding controller may comprise a processor (e.g. a microprocessor). It will be appreciated that any references herein to the flux feeding controller carrying out a particular function encompass the processor (e.g. microprocessor) carrying out said function. The processor (e.g. microprocessor) may be in electronic communication with a memory storing instructions (e.g. a computer program in the form of computer executable program code) configured to cause the processor (e.g. microprocessor) to carry out said function.

The flux feeding controller may be a programmable logic controller (PLC). The flux feeding controller may be part of a supervisory control and data acquisition (SCADA) system.

The controller and the flux feeding controller may form part of the same control module. The controller and the flux feeding controller may form part of the same SCADA system. The controller may be the flux feeding controller, i.e. the method may comprise a (i.e. single) controller: (a) operating the one or more actuators to move the one or more flux outlets relative to the mold; and (b) setting the one or more operating parameters for the flux feeding apparatus.

The method may further comprise regulating a temperature of the one or more actuators and/or the controller and/or the flux feeding controller. The method may comprise cooling the one or more actuators and/or the controller and/or the flux feeding controller. The method may comprise generating an air flow around the one or more actuators and/or the controller and/or the flux feeding controller, i.e. to thereby cool the one or more actuators and/or the controller and/or the flux feeding controller.

The skilled person will appreciate that, except where mutually exclusive, a feature described in relation to any one of the above aspects may be applied *mutatis mutandis* to any other aspect. Furthermore, except where mutually exclusive, any feature described herein may be applied to any aspect and/or combined with any other feature described herein.

Figures

Embodiments will now be described by way of example only, with reference to the Figures, in which:

Figure 1 is a plan view of an example continuous casting apparatus;

Figure 2 is a sectional view of the example continuous casting apparatus of Figure 1 along A-A;

Figure 3 is an alternative sectional view of the example continuous casting apparatus of Figure 1 along B-B;

Figure 4 is a plan view of the example continuous casting apparatus of Figure 1 during use;

Figure 5 shows (a) plan, (b) first side and (c) second side views of an example flux distribution apparatus including flux feeding tubes;

Figure 6 shows (a) plan and (b) sectional views of the example flux distribution apparatus of Figure 5 without flux feeding tubes attached;

Figure 7 is a perspective view of a portion of the example flux distribution apparatus of Figures 5 and 6;

Figure 8 shows (a) first side, (b) second side and (c) perspective views of an example controller for a flux distribution apparatus;

Figure 9 is a plan view of the example continuous casting apparatus of Figure 1 incorporating a flux feeding controller and sensor; and

Figure 10 is a plan view of the example continuous casting apparatus of Figure 1 incorporating a temperature regulation module.

Detailed description

With reference to Figures 1, 2 and 3, a continuous casting apparatus 1 includes a mold 2, a molten metal delivery apparatus 3 for delivering molten metal into the mold 2, and a flux delivery apparatus 4 for delivering flux into the mold 2. Figure 1 is a plan view (i.e. a view from above) of the continuous casting apparatus 1. Figures 2 and 3 are sectional views through the continuous casting apparatus 1 along lines A-A and B-B indicated in Figure 1.

As shown in Figures 1 and 2, the molten metal delivery apparatus 3 comprises a ladle 5 and a tundish 6. The tundish 6 is positioned above the mold 2 and is configured to feed molten metal into the mold 2 through subentry nozzle 7. Molten metal is delivered periodically into the tundish 6 by the ladle 5. In use, molten metal, which is delivered into the mold 2 continuously from the tundish 6, cools and begins to solidify within the mold, thereby forming a strand 9. The continuous casting apparatus 1 includes rollers 8 for conveying a solidying metal strand 9 away from the mold 2. It will be appreciated that the continuous casting apparatus may be used to cast a strand of any metal suitable for continuous casting, such as steel. The mold 2 may be made of any suitable material, for example copper. The mold 2 may be water-cooled. The continuous casting apparatus 1 may be suitable for casting slabs, billets or blooms.

As shown in Figures 1 and 3, the flux delivery apparatus 4 includes two flux feeding tubes 10A and 10B for delivering flux 12 to the mold 2 by way of corresponding flux outlets 11A and 11B. The flux feeding tubes 10A and 10B are rigid and made of any suitable metal such as stainless steel. The flux feeding tubes 10A and 10B are connected to a flux storage 14 by way of flux feeding hoses 13A and 13B. The flux feeding hoses 13A and 13B are flexible and made of any suitable material such as rubber. The flux delivery apparatus includes a pump (not shown) for pumping flux from the flux storage 14, through the flexible flux feeding hoses 13A and 13B, and through the flux feeding tubes 10A and 10B, towards the flux outlets 11A and 11B for distribution within the mould 2. The flux outlets 11A and 11B may include flux distributors (not shown).

It will be appreciated that flux 12 (also known as mold flux, casting flux, mold powder or casting powder) is an engineered material, typically comprising oxides, minerals and carbonaceous materials, which forms a slag when heated by molten metal in the mold 2. For example, the flux 12 may include silica, bauxite, calcium silicate/wollastonite, feldspar, soda ash, fluorspar, lithium carbonate, etc., or any combination thereof. At the zone of contact with liquid metal, the flux 12 serves to prevent reoxidation and avoid heat loss so as to prevent premature solidification of the liquid metal. The flux 12 also absorbs non-metallic inclusions at the liquid slag-metal interface, thereby producing cleaner metal. Further, at the zone of contact with solidified metal, the flux 12 provides lubrication between the solidified metal shell and the mold 2. The flux 12 also plays an important role in controlling heat transfer, particularly in a horizontal direction.

In flux delivery apparatus 4, the flux feeding tubes 10A and 10B are movably mounted on a base 15. The base 15 includes a mechanism (not shown in Figures 1, 2 and 3) for driving movement of the flux feeding tubes 10A and 10B, and therefore of the flux outlets 11A and 11B, relative to the mold 2. The flux delivery apparatus also includes a controller 16 configured to operate the mechanism to control the movement of the flux feeding tubes 10A and 10B. The base 15 and controller 16 therefore function together as a robotic arm for controlling movement of the flux feeding tubes 10A and 10B. By moving the flux feeding tubes 10A and 10B, and therefore moving the flux outlets 11A and 11B, relative to the mold 2, the positions at which flux 12 enters the mold 2 can be varied. Accordingly, the distribution of flux 12, and the resultant slag, within the mold 2 can be controlled.

In the example shown in Figures 1 to 3, the mechanism is operable to move the flux feeding tubes 10A and 10B back and forth along an axis parallel to an axis of the mold 2 (and perpendicular to a respective longitudinal axis of each flux feeding tube 10A and 10B). For example, Figure 4 illustrates movement of the flux feeding tubes 10A and 10B, in the directions indicated by arrows 17A and 17B, between a first position (drawn in solid lines) and a second position (drawn in dashed lines). By moving the flux feeding tubes 10A and 10B between the first and second positions, while flux is pumped into the mold 2 through the flux outlets 11A and 11B, flux is distributed within the mold 2 between the first and second positions. This results in a more even distribution of flux within the mold 2 than could be achieved by pumping flux into the mold 2 via static flux feeding tubes, thereby reducing the effects of known problems such as hip formation (i.e., flux powder layer depth fluctuations within the mold), slag entrapment, meniscus deformation, steel carbonization and uneven fusion. Accordingly, entrapment breakout is reduced, as is slag rim formation, and oscillation mark formation is improved.

Figures 5, 6 and 7 illustrate an example mechanism for achieving the type of movement illustrated in Figure 4. In this example, flux feeding tubes 10A and 10B are mounted to the base 15 by way of corresponding brackets 18A and 18B, each bracket attached to a corresponding carriage 19A and 19B which is mounted on a corresponding leadscrew 20A and 20B housed within the base 15. A motor 21, positioned at a first end of the base 15, is operatively connected to the leadscrew 20A to drive rotation thereof, rotation of the leadscrew 20A in turn causing movement of carriage 19A along the longitudinal axis of the base 15, the direction of movement of the carriage 19A being dependent on the sense in which the leadscrew 20A is turned. Leadscrew 20A is operatively coupled to leadscrew 20B by a central gear mechanism 22 such that rotation of leadscrew 20A in a first sense drives rotation of leadscrew 20B in a second sense opposite said first sense. Accordingly, operation of the motor 21 causes leadscrews 20A and 20B to rotate in opposing senses and, consequently, carriages 19A and 19B to move in opposing directions along the longitudinal axis of the base 15. The motor 21 and the leadscrews 20A and 20B therefore function together as an actuator for actuating movement of the flux feeding tubes 10A and 10B (and therefore corresponding movement of the flux outlets 11A and 11B) along the longitudinal axis of the base 15 (and therefore parallel to the major axis of the mold 2 (when viewed from above), due to the positioning of the base 15). It will be appreciated that varying the operation of the motor to alternate the senses in which leadscrews 20A and 20B rotate drives reciprocating movement of the flux feeding tubes 10A and 10B (and therefore corresponding reciprocating movement of the flux outlets 11A and 11B) back and forth relative to the mold 2. In some examples, the motor 21 is a servomotor including an encoder for monitoring the movement of leadscrews 20A and 20B. In some examples, the controller 16 includes a servomechanism for monitoring and controlling the movement of the leadscews 20A and 20B.

While Figures 5, 6 and 7 illustrate one particular example mechanism for achieving movement of the flux feeding tubes 10A and 10B along the base 15, it will be appreciated that any suitable type of actuator known in the art (such as mechanical actuators (including electromechanical actuators), hydraulic actuators or pneumatic actuators) may be used to drive movement of the flux feeding tubes 10A and 10B and/or the flux outlets 11A and 11B. In some examples, as in the example illustrated in Figures 5, 6 and 7, the mechanism uses one or more linear actuators to actuate linear movement of the flux feeding tubes 10A and 10B and/or the flux outlets 11A and 11B. However, it will be appreciated that other types of actuator, such as rotatory actuators, may be used in addition to or instead of linear actuators.

It will also be appreciated that the number and placement of the flux feeding tubes (and consequently the number and placement of the flux outlets) can be varied. For example, the apparatus made include one (i.e. single) flux feeding tube or two or more (e.g. three or more, four or more, etc.) flux feeding tubes located at different positions.

In addition, it will be appreciated that the one or more flux feeding tubes and/or the corresponding flux outlets may be moved in any direction relative the mold 2, dependent on the type of actuator(s) used and the configuration of said actuator(s). In some examples, the flux delivery apparatus comprises actuators configured to drive movement of the flux feeding tubes and/or the along a single axis. For example, the flux delivery apparatus may comprise one or more actuators configured to drive movement of the flux feeding tubes and/or the flux outlets along a first axis substantially parallel to an axis of the mold 2 (e.g. along the longitudinal axis of the base 15). Movement of the flux feeding tubes and/or the flux outlets substantially parallel to the axis of the mold 2 enables the location(s) at which flux is fed into the mold to be varied. In some examples, the flux delivery apparatus comprises one or more actuators configured to drive movement of the flux feeding tubes and/or the flux outlets along a second axis which extends substantially horizontally and substantially perpendicular to the axis of the mold 2. Movement of the flux feeding tubes and/or the substantially horizontally and perpendicular to the axis of the mold 2 enables the flux outlets to be extended towards the mold 2 or retracted away from the mold 2, thereby enabling accurate positioning of the flux outlets above the mold 2. In some examples, the flux delivery apparatus comprises one or more actuators configured to drive movement of the flux feeding tubes and/or the flux outlets along a third axis which is substantially vertical. Movement of the flux feeding tubes and/or the flux outlets along a substantially vertical axis enables control of the height at which the flux outlets are positioned above the mold 2. It will be appreciated that one or more actuators may be configured (for example, by combining two or more actuators in different arrangements) to enable control of the movement of the flux feeding tubes and/or the flux outlets in any combination of directions, for example substantially in the horizontal (i.e. X-Y) plane or in three dimensions (i.e. X-Y-Z movement control).

As explained hereinabove, by moving the flux feeding tubes, and therefore moving the flux outlets, relative to the mold 2, the locations at which flux 12 enters the mold 2 can be varied. Accordingly, the distribution of flux 12 (and the resultant slag) within the mold 2 can be controlled. In the example shown in Figure 1, the flux delivery apparatus includes a controller 16 configured to operate the mechanism for controlling the movement of the flux feeding tubes 10A and 10B. In this example, the controller 16 is a programmable logic controller (PLC) of the type shown in Figure 8, which includes a user interface (in the form of a human-machine interface (HMI)) 23, a lock 24, an emergency stop switch 25 (actuation of which causes operation of the device to stop), a power supply (not shown) and a processor (not shown) configured to control operation of the one or more actuators for driving movement of the flux feeding tubes 10A and 10B.

The controller 16 may be configured to operate the mechanism for controlling the movement of the flux feeding tubes 10A and 10B in many different ways. In the example shown in Figure 4, the controller 16 is configured to move the flux feeding tubes 10A and 10B cyclically (i.e. back and forth) and in opposing directions between first and second positions. However, in other examples, the controller 16 may be configured to hold flux feeding tubes in particular locations, for example for set periods of time, and to periodically move the flux feeding tubes to different locations spaced apart along the mold 2. In some examples, the controller 16 may be configured to move two or more of the flux feeding tubes in opposing directions, while in other examples the controller 16 may be configured to move two or more of the flux feeding tubes in the same direction. In some examples, the controller 16 may be configured to move two or more of the flux feeding tubes at the same time (i.e. concurrently), while in other examples, the controller 16 is configured to move two or more of the flux feeding tubes at different times (i.e. individually or sequentially).

The controller 16 may be configured (e.g. programmed) to operate the mechanism for controlling the movement of the flux feeding tubes according to one or more predetermined movement patterns (for example, stored on a memory within the controller 16). In some examples, a movement pattern is selected by a user, for example by way of the user interface 23. In some examples, the controller 16 selects an appropriate movement pattern based on one or more inputs, which may be one or more user inputs (for example, input by way of the user interface 23). In some examples, the controller 16 sets one or more operating parameters for the mechanism (e.g. for one or more actuators forming part of the mechanism), such as a direction of travel, a travel distance and/or a speed of travel. The controller 16 may set the one or more operating parameters based on or more inputs, which may be one or more user inputs (for example, input by way of the user interface 23), such as an input indicative of a dimension (e.g. a width) of the mold 2 or a casting speed. For example, the controller 16 may set the travel distance (i.e. the stroke length) for moving the flux feeding tubes 10A and 10B based on the width of the mold 2 (which may vary during a continuous casting process). Additionally or alternatively, the controller 16 may set the speed of travel for moving the flux feeding tubes 10A and 10B based on the casting speed.

In the example shown in Figure 9, the flux delivery apparatus 4 further includes a sensor 26 and a flux feeding controller 27. The sensor 26 is operable to measure a casting process parameter, such as a grade of metal being cast, a casting speed, a flux consumption rate, a heat transfer rate, a flux type, a slag temperature, a metal temperature, a metal flow condition, a flux thickness, a slag thickness, a mold width, a section size and/or a taper. It will be appreciated that any type of sensor known in the art and suitable for measuring the relevant casting process parameter may be used. For example, the sensor 26 may be a temperature sensor, a laser measurement device, an ultrasonic measurement device, an infrared sensor, a thermal imaging sensor and/or microwave sensor. It will be appreciated that outputs from different types of sensor can be combined to monitor aspects of the continuous casting process. For example, outputs from a temperature sensor can be combined with outputs from a laser measurement device, which measures a flux profile within the mold, to monitor flow variations within the mold 2 (which lead to temperature differences) and bias flow (i.e. plugging conditions) of the sub-entry nozzle (by comparing temperature measurements either side of the sub-entry nozzle).

The sensor 26 is connected to the flux feeding controller 27 and configured to output a signal to the flux feeding controller 27 indicative of the measured casting process parameter. The flux feeding controller 27 is in turn operatively coupled to the pump (not shown) for controlling the feeding of flux from the flux container 14, through the flexible hoses 13A and 13B, and through the flux feeding tubes 10A and 10B, to the flux outlets 11A and 11B, dependent on the signal received from the sensor.

In some examples, the flux feeding controller 27 is configured to vary the rate at which flux is pumped to the flux outlets 11A and 11B dependent on the signal received from the sensor 27. For example, in response to a signal from the sensor 26 indicating that a flux thickness within the mold 2 is higher than a threshold, the flux controller 27 may reduce the rate at which flux is pumped into the mold 2. In some examples, the flux controller 27 may vary the rate at which flux is pumped into the mold 2, dependent on the position of the flux feeding tubes 10A and 10B, so as to achieve an even distribution of flux within the mold 2, for example by increasing the rate at which flux is pumped into the mold 2 when the flux outlets 11A and 11B are located at regions of the mold 2 having relatively less flux and decreasing the rate at which flux is pumped into the mold 2 (including stopping pumping flux into the mold 2) when the flux outlets 11A and 11B are located at regions of the mold 2 having relatively more flux. In some examples, the flux controller 27 may determine the rate at which flux is pumped into the mold 2 so as to achieve a substantially uniform layer of unmelted flux across the mold 2, thereby establishing or maintaining steady state conditions within the mold 2.

In some examples, the controller 16 and the flux feeding controller 27 form part of the same control module. In some examples, a single controller performs the roll of the controller 16 and the flux feeding controller 27.

In some examples, the flux delivery apparatus 4 includes a temperature regulation module for regulating a temperature of the controller and/or any motors and/or actuating elements. For example, the flux delivery apparatus 4 may include an air mover for blowing air through the apparatus, for example in response to an output from a temperature sensor indicating that a temperature has exceeded a threshold. Circulating air within the apparatus, in particular to cool any motors and/or actuating elements (such as leadscrews) ensures that the said component operate according to standard settings and reduces wear and tear. For example, Figure 10 shows a flux delivery apparatus 4 which includes a temperature regulation module in the form of an air mover 28 (which may include an air pressure regulator), for generating a flow of air through the base 15 to cool the mechanism inside. The example shown in Figure 10 also includes an air exhaust, 29, including a silencer. In other examples, the temperature regulation module can generate a flow of argon, nitrogen, compressed air or any other suitable gas in order to cool the apparatus.

It will be understood that the invention is not limited to the embodiments described above and various modifications and improvements can be made without departing from the concepts described herein. Except where mutually exclusive, any of the features described hereinabove may be employed separately or in combination with any other features and the disclosure extends to and includes all combinations and sub-combinations of one or more features described herein.

Claims

1. A flux delivery apparatus for delivering flux to a mold during a continuous casting process, the flux delivery apparatus comprising:

   one or more flux outlets for delivering flux to the mold;

   one or more actuators operable to actuate movement of the one or more flux outlets relative to the mold; and

   a controller configured to operate the one or more actuators to move the one or more flux outlets relative to the mold.

2. The flux delivery apparatus according to claim 1 comprising at least first and second flux outlets for delivering flux to the mold, the one or more actuators being operable to actuate movement of the first and second flux outlets relative to the mold and the controller being configured to operate the one or more actuators to move the first and second flux outlets relative to the mold, for example in opposing directions.

3. The flux delivery apparatus according to claim 1 or claim 2, wherein the one or more actuators are operable to actuate movement of the one or more flux outlets along or parallel to a first axis, and wherein the one or more actuators are optionally further operable to actuate movement of the one or more flux outlets along or parallel to a second axis angled with respect to, for example orthogonal to, the first axis.

4. The flux delivery apparatus according to claim 3, wherein the one or more actuators comprise one or more linear actuators operable to actuate linear movement of the one or more flux outlets along or parallel to the first axis and/or the second axis, for example wherein the one or more linear actuators comprise one or more leadscrews for actuating linear movement of the one or more flux outlets along or parallel to the first axis and/or the second axis.

5. The flux delivery apparatus according to any preceding claim comprising one or more flux feeding tubes for feeding flux to the one or more flux outlets from a flux storage, for example wherein the one or more flux outlets each correspond to one or more respective open ends of the one or more flux feeding tubes, optionally

wherein the flux delivery apparatus comprises the flux storage and/or a pump for pumping flux from the flux storage, through the one or more flux feeding tubes, to the one or more flux outlets.

6. The flux delivery apparatus according to any preceding claim, wherein the controller is configured to set one or more operating parameters for the one or more actuators based at least in part on one or more control inputs, for example wherein the one or more operating parameters for the one or more actuators include a direction of travel, a travel distance and/or a speed of travel for the one or more actuators and/or the one or more flux outlets moved by the one or more actuators,

optionally wherein the flux delivery apparatus further comprises a user interface for supplying the controller with one or more user inputs, for example one or more control inputs.

7. The flux delivery apparatus according to any preceding claim further comprising flux feeding apparatus for feeding flux to the one or more flux outlets from a flux storage and a flux feeding controller configured to set one or more operating parameters for the flux feeding apparatus based at least in part on one or more casting process inputs indicative of one or more casting process parameters, for example wherein the one or more casting process parameters include a grade of metal being cast, a casting speed, a flux consumption rate, a heat transfer rate, a flux type, a slag temperature, a metal temperature, a metal flow condition, a flux thickness, a slag thickness, a mold width, a section size and/or a taper,

optionally wherein the flux delivery apparatus further comprises one or more sensors for measuring one or more casting process parameters and supplying the flux feeding controller with one or more sensor inputs indicative of the measured casting process parameters, for example wherein the one or more sensors include one or more temperature sensors, laser measurement devices, ultrasonic measurement devices, infrared sensors, thermal imaging sensors and/or microwave sensors.

8. The flux delivery apparatus according to any preceding claim further comprising a temperature regulation apparatus for regulating the temperature of the one or more actuators and/or the controller.

9. A flux delivery support apparatus for a continuous casting process, the flux delivery support apparatus comprising:

   one or more supports for supporting one or more flux outlets and/or one or more flux feeding tubes for delivering flux to a mold;

   one or more actuators operable to actuate movement of the one or more supports relative to the mold; and

   a controller configured to operate the one or more actuators to move the one or more supports relative to the mold.

10. The flux delivery support apparatus according to claim 9 comprising at least first and second supports for supporting at least first and second flux outlets and/or flux feeding tubes for delivering flux to the mold, the one or more actuators being operable to actuate movement of the first and second supports relative to the mold and the controller being configured to operate the one or more actuators to move the first and second supports relative to the mold, for example in opposing directions.

11. A continuous casting apparatus comprising the flux delivery apparatus according to any of claims 1 to 8 or the flux delivery support apparatus according to claim 9 or claim 10.

12. A method of delivering flux to a mold during a continuous casting process, the method comprising:

   positioning one or more flux outlets at the mold;

   delivering flux into the mold through the one or more flux outlets; and

   moving the one or more flux outlets relative to the mold to distribute the flux within the mold.

13. The method according to claim 12 comprising:

   positioning at least first and second flux outlets at the mold;

   delivering flux into the mold through the first and second flux outlets; and

   moving the first and second flux outlets, for example in opposing directions, relative to the mold to distribute the flux within the mold.

14. The method according to claim 12 or claim 13 comprising a controller operating one or more actuators to move the one or more flux outlets relative to the mold.

15. The method according to claim 14 comprising:

(a) the controller setting one or more operating parameters for the one or more actuators based at least in part on one or more control inputs, for example wherein the one or more operating parameters for the one or more actuators include a direction of travel, a travel distance and/or a speed of travel for the one or more actuators and/or the one or more flux outlets moved by the one or more actuators; and/or

(b) a flux feeding controller setting one or more operating parameters for a flux feeding apparatus, for feeding flux to the one or more flux outlets from a flux storage, based at least in part on one or more casting process inputs indicative of one or more casting process parameters, for example wherein the one or more casting process parameters include a grade of metal being cast, a casting speed, a flux consumption rate, a heat transfer rate, a flux type, a slag temperature, a metal temperature, a metal flow condition, a flux thickness, a slag thickness, a mold width, a section size and/or a taper.

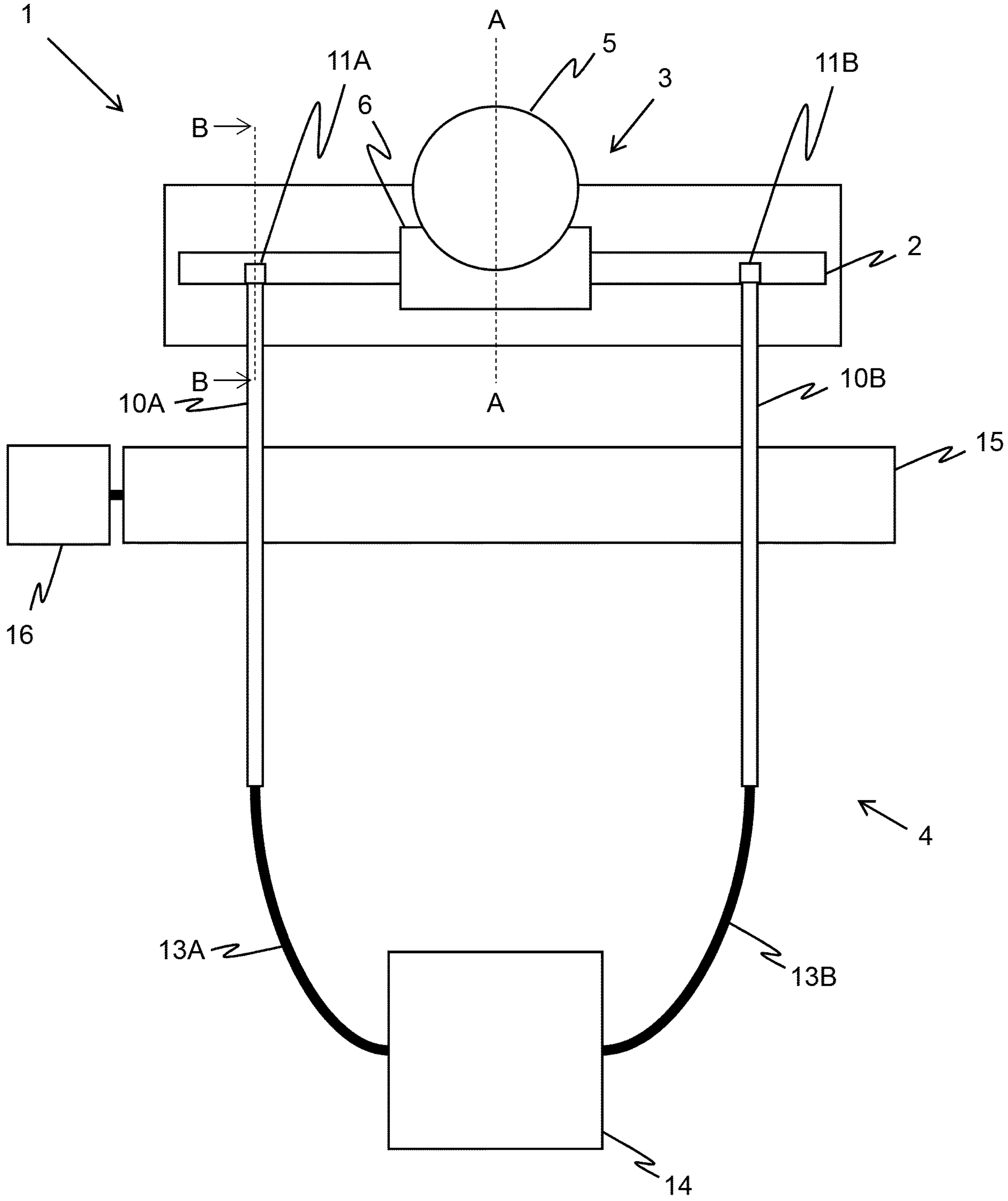

Fig. 1

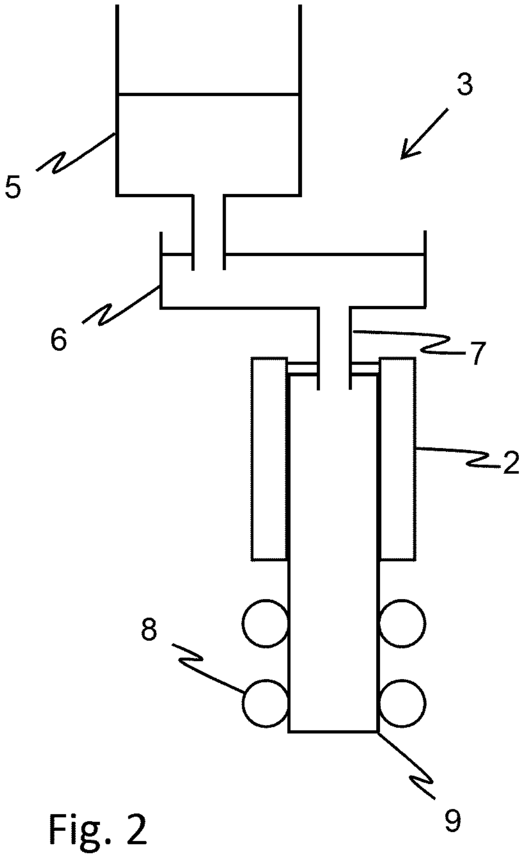

Fig. 2

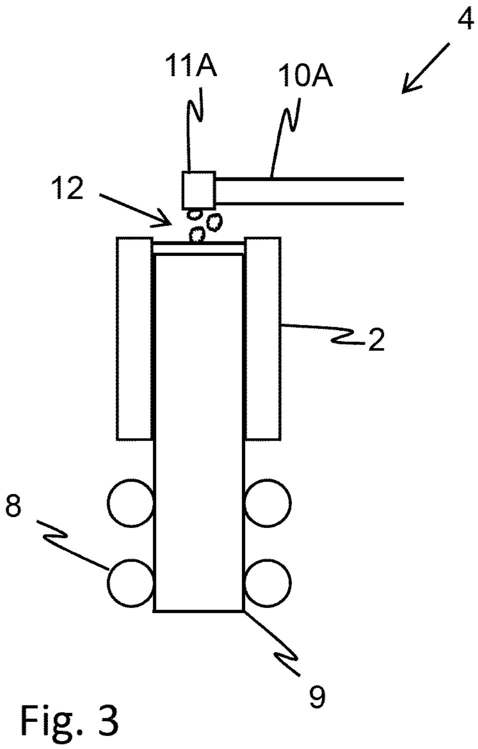

Fig. 3

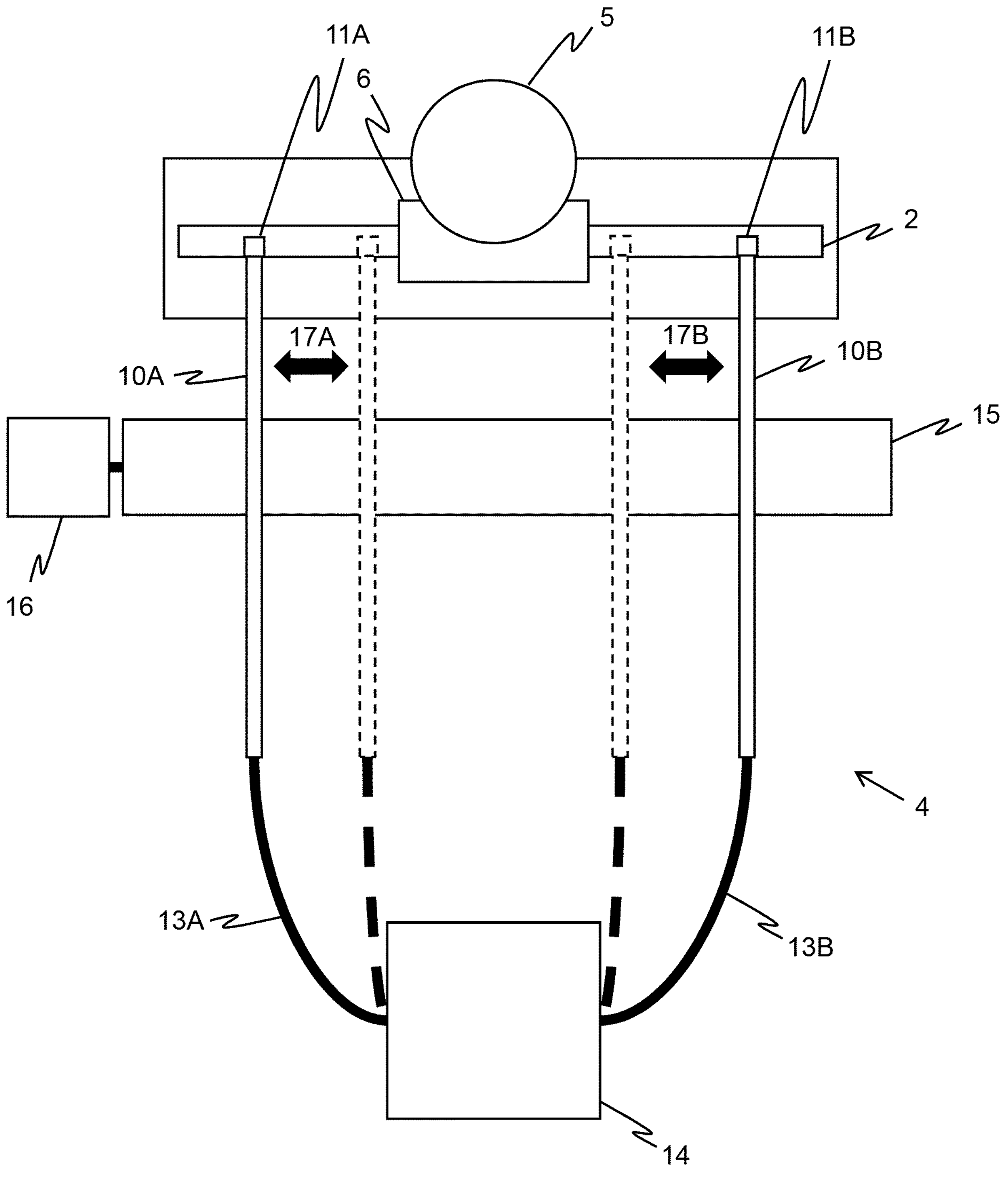

Fig. 4

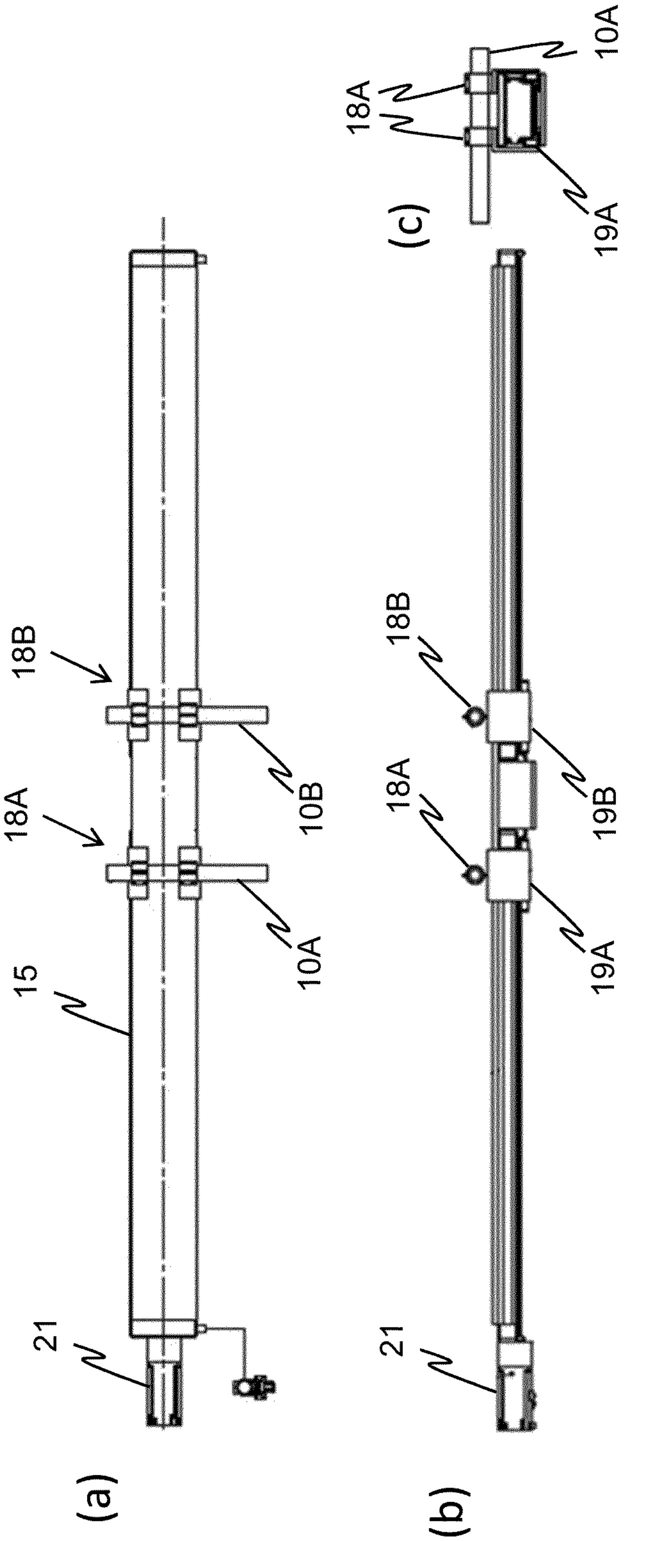

Fig. 5

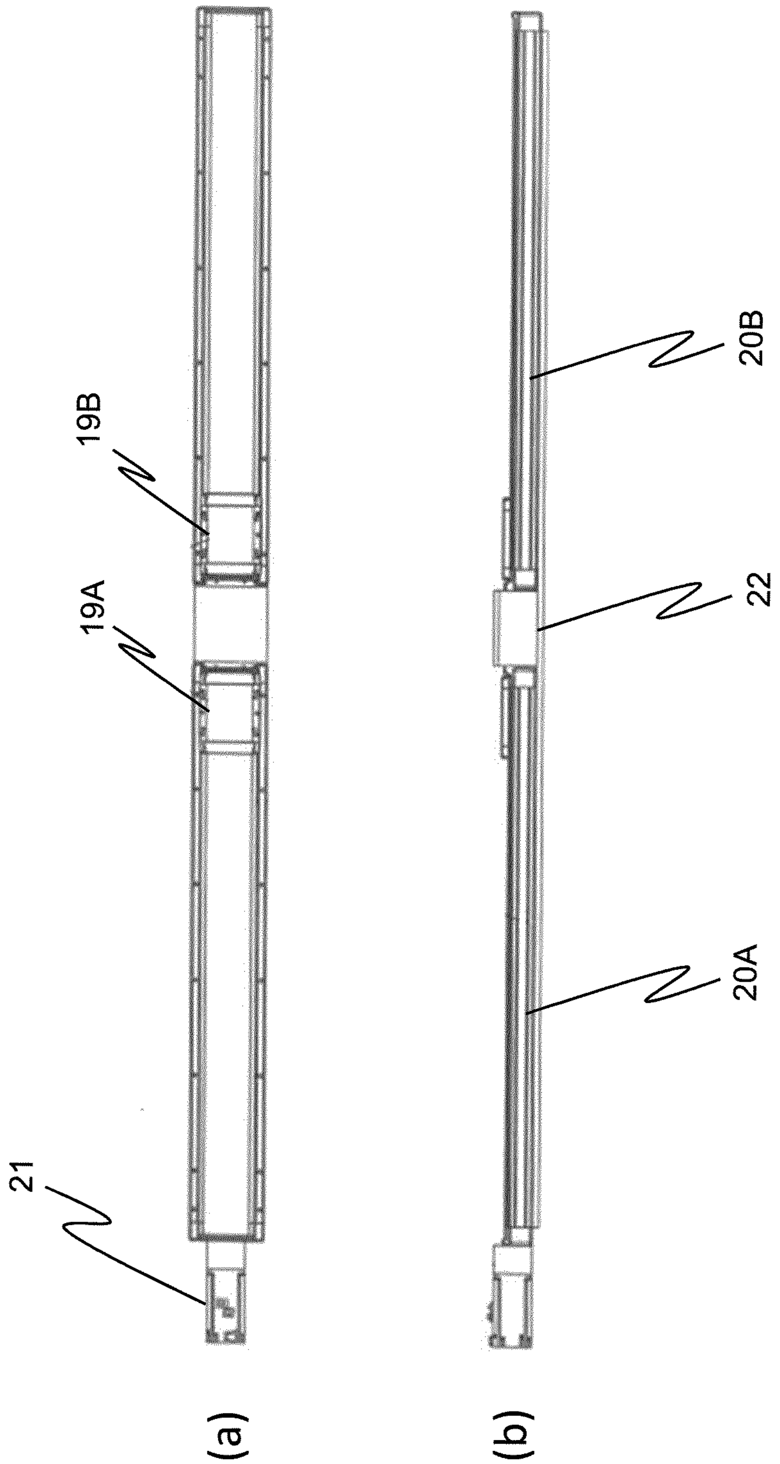

Fig. 6

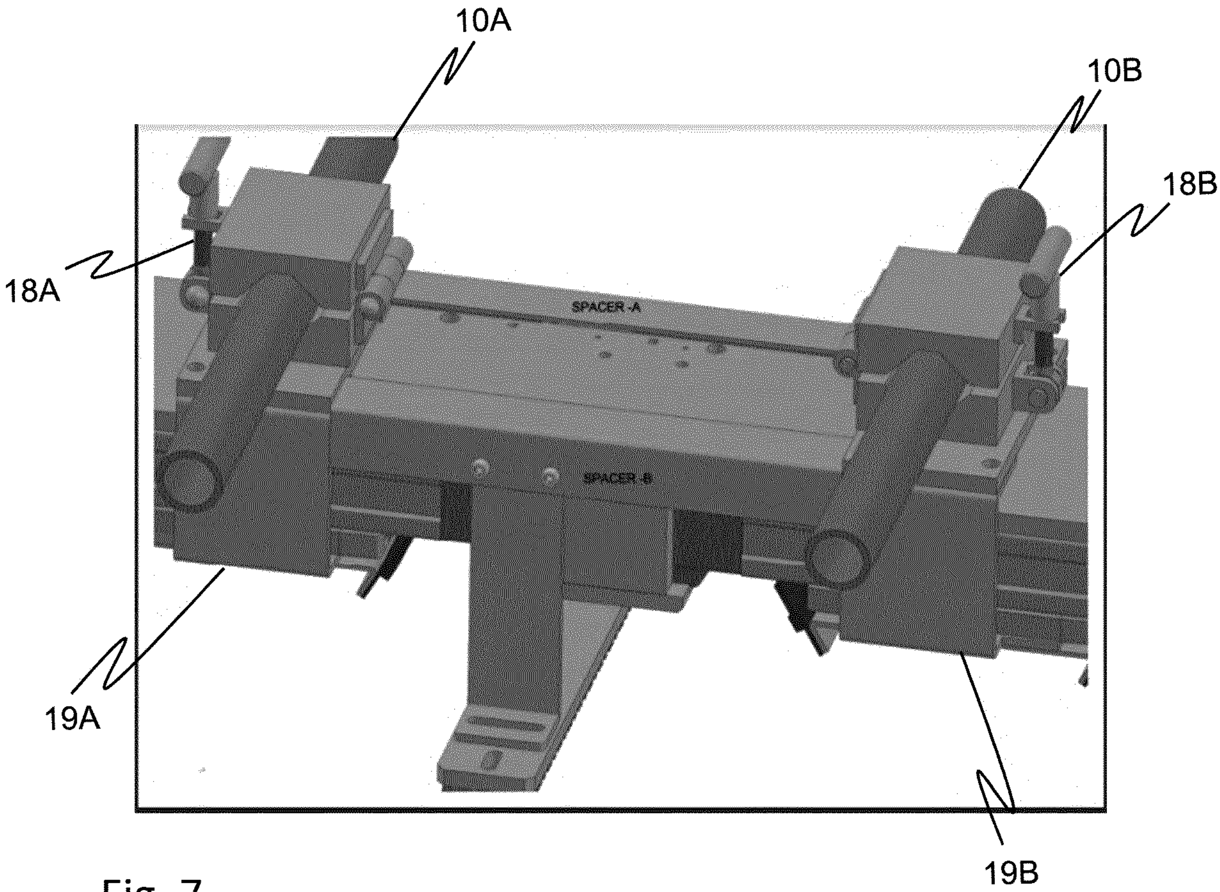

Fig. 7

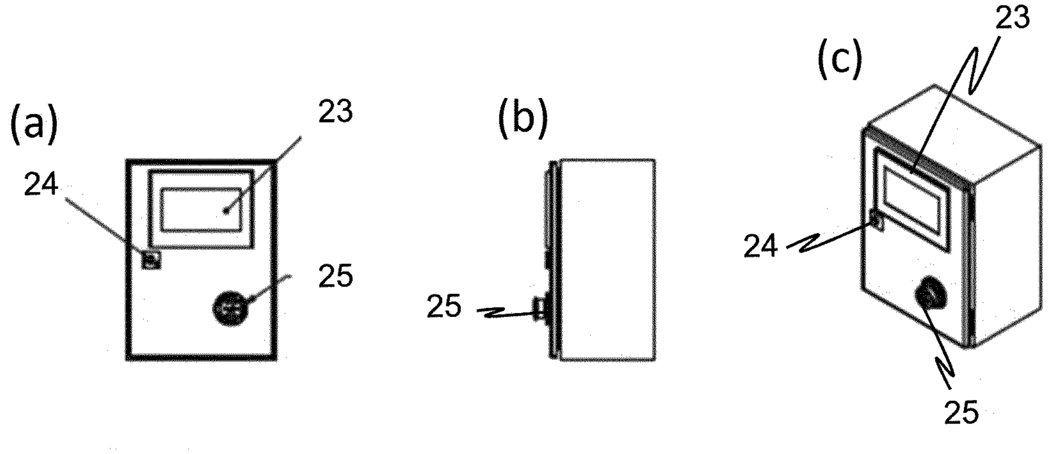

Fig. 8

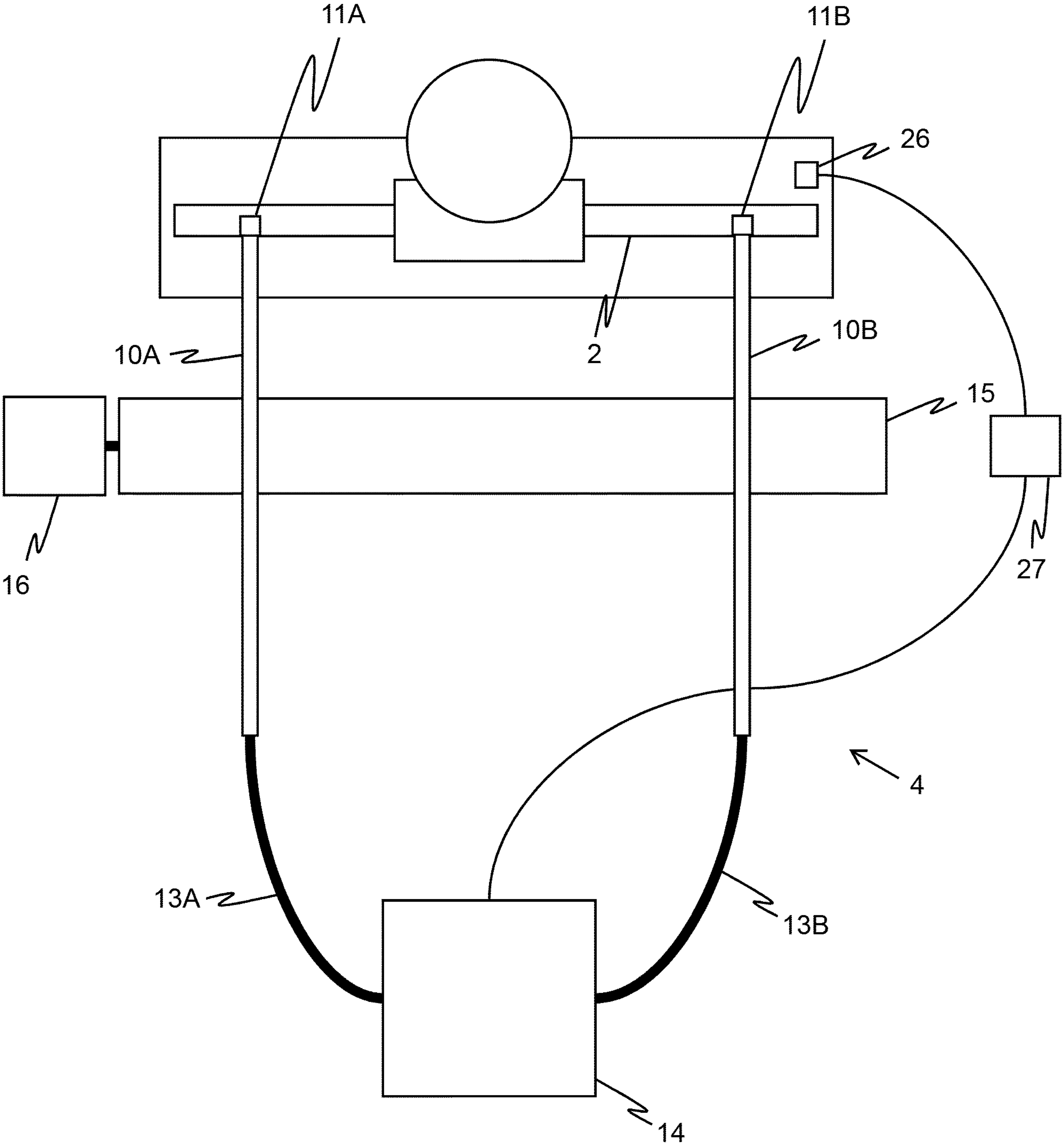

Fig. 9

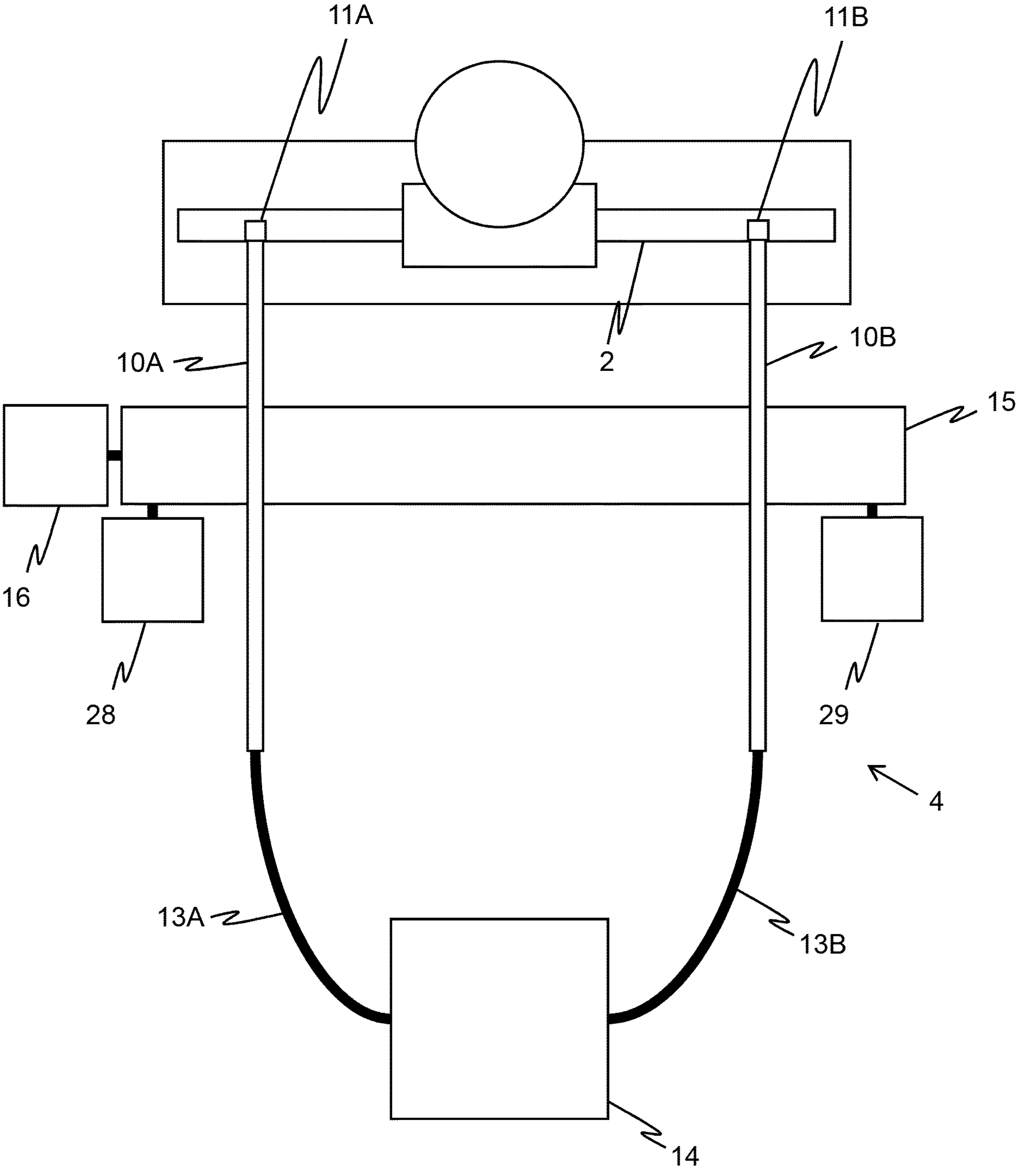

Fig. 10

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2021/069456

A. CLASSIFICATION OF SUBJECT MATTER
INV. B22D11/07 B22D11/108 B22D11/111 B22D11/16
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B22D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GB 2 026 418 A (WIEGARD MASCHF GUSTAV; MANNESMANN AG) 6 February 1980 (1980-02-06) figures 1-3 page 1, line 1 - page 1, line 54 page 1, line 63 - page 2, line 17 -----	1-15
X	WO 2011/110615 A2 (SIEMENS VAI METALS TECH GMBH [AT]; EBNER HELMUT [AT] ET AL.) 15 September 2011 (2011-09-15) figures 1-9 page 1, line 1 - line 15 page 2, line 21 - page 7, line 15 page 8, line 1 - page 9, line 32 -----	1-15
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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

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"P" document published prior to the international filing date but later than the priority date claimed

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Date of the actual completion of the international search	Date of mailing of the international search report
16 September 2021	27/09/2021

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Jung, Régis

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INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2021/069456

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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