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STALDER et al.(10) **Pub. No.: US 2017/0182552 A1**(43) **Pub. Date: Jun. 29, 2017**(54) **METHOD FOR OPERATING A VACUUM
DIE-CASTING MACHINE****B22D 17/14** (2006.01)**B22D 17/10** (2006.01)(71) Applicant: **BÜHLER AG**, Uzwil (CH)(52) **U.S. Cl.**CPC **B22D 17/32** (2013.01); **B22D 17/10**
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Roman KERN, St. Gallen (CH)(21) Appl. No.: **15/308,677**

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A method of determining the position of at least one opening (9, 10) in a casting chamber (6) of a die-casting machine (1), wherein a casting plunger (7) is contained in the casting chamber (8). The casting plunger (7) is movable into a position in which communication between the opening (9, 10) and the casting chamber (6) is no longer possible. It is determined, on the basis of the vacuum in the connecting line (14, 15), when the casting plunger (7) has reached the position in which communication, between the opening (9, 10) and the casting chamber (6), is no longer possible. A method of operating a vacuum die-casting machine, wherein a casting curve, for performing a casting cycle, is determined by specified and/or experimentally determined characteristic values of the die-casting machine by a computer program for operating the die-casting machine, and to a corresponding computer program product.

Fig. 1

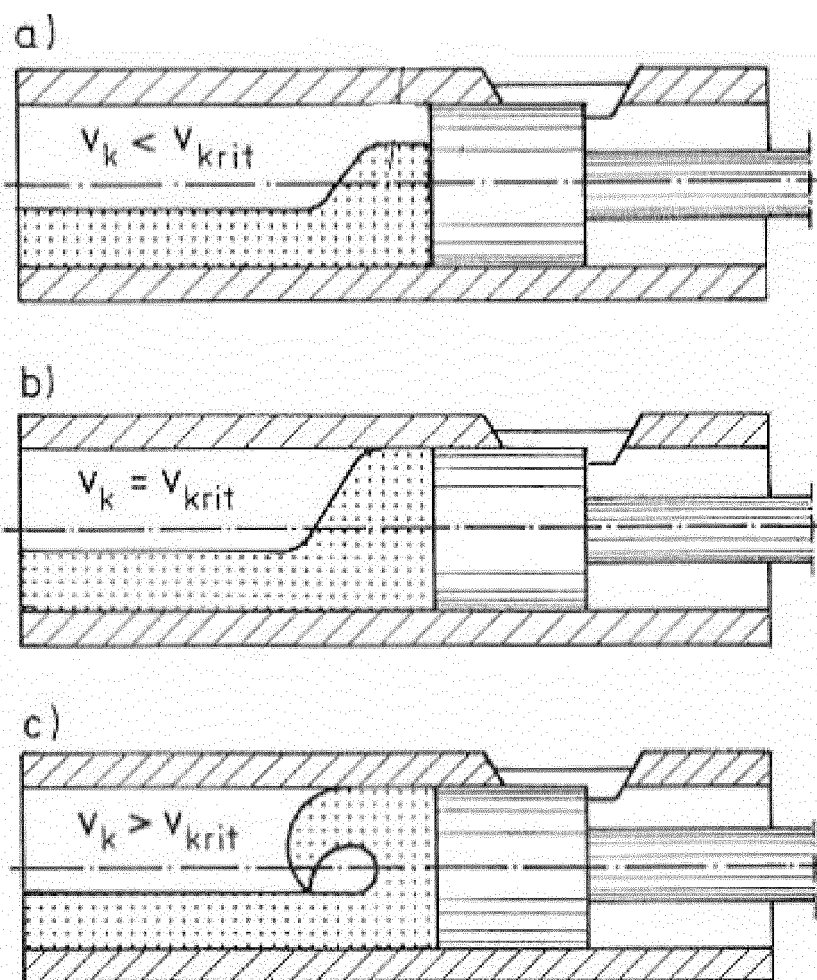


Fig. 2

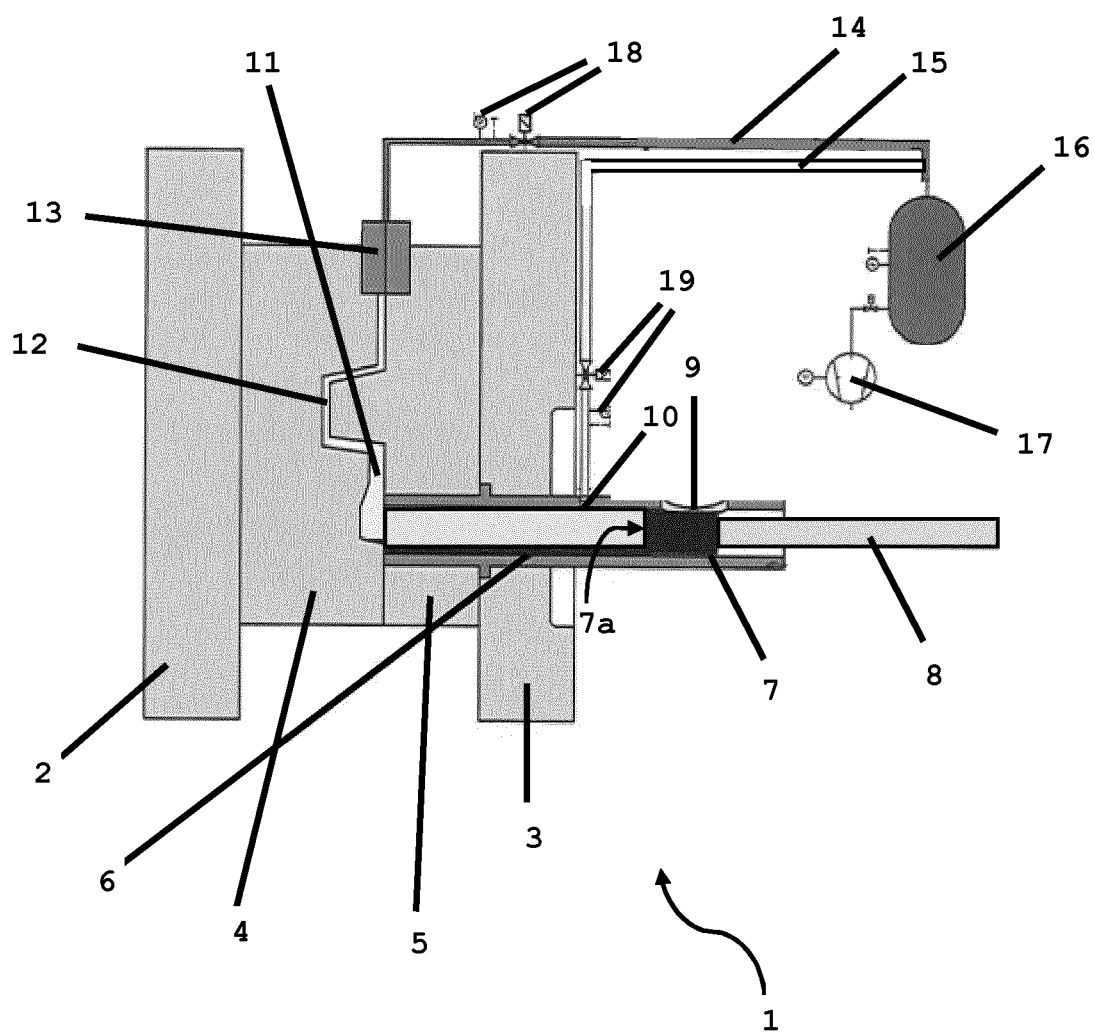


Fig. 3

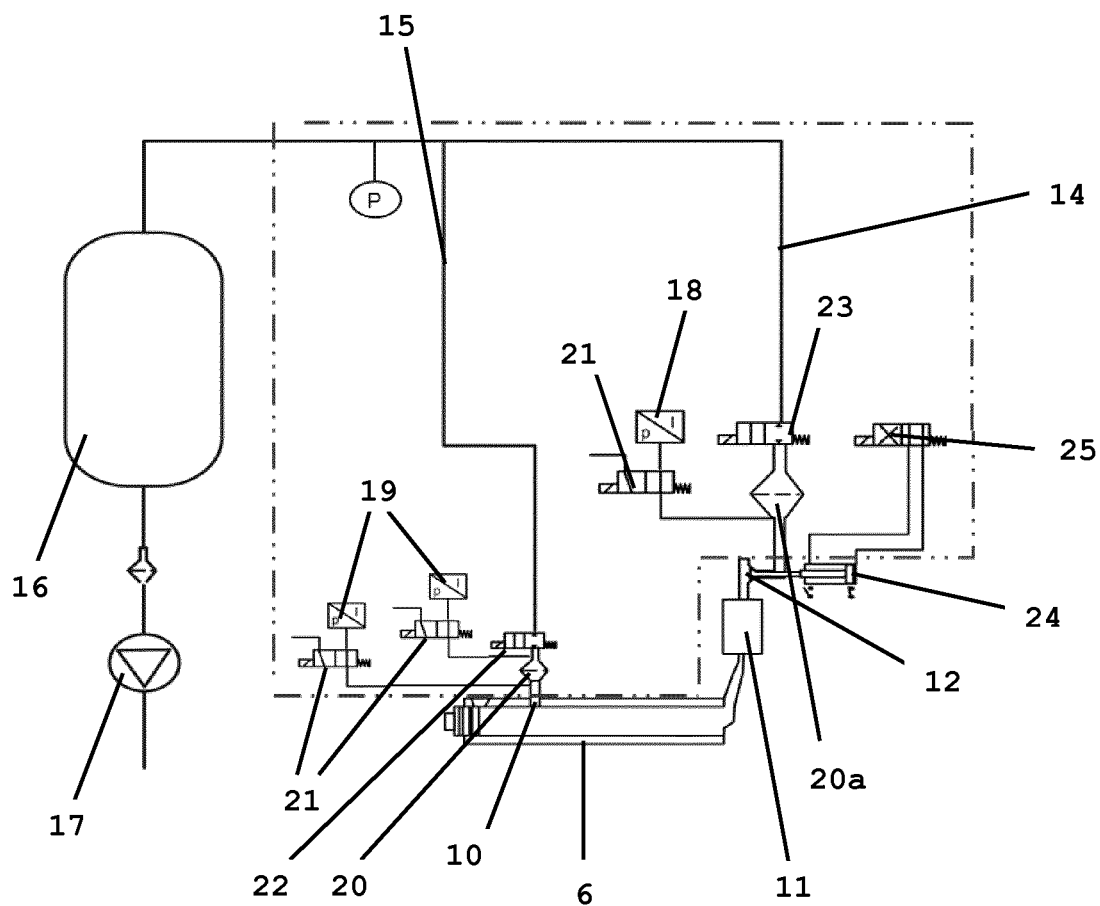


Fig. 4

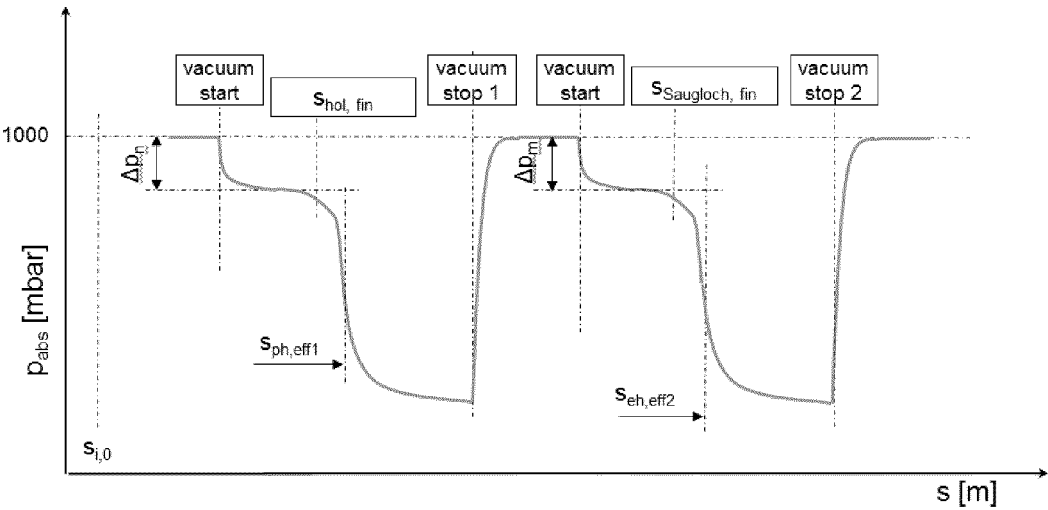


Fig. 5

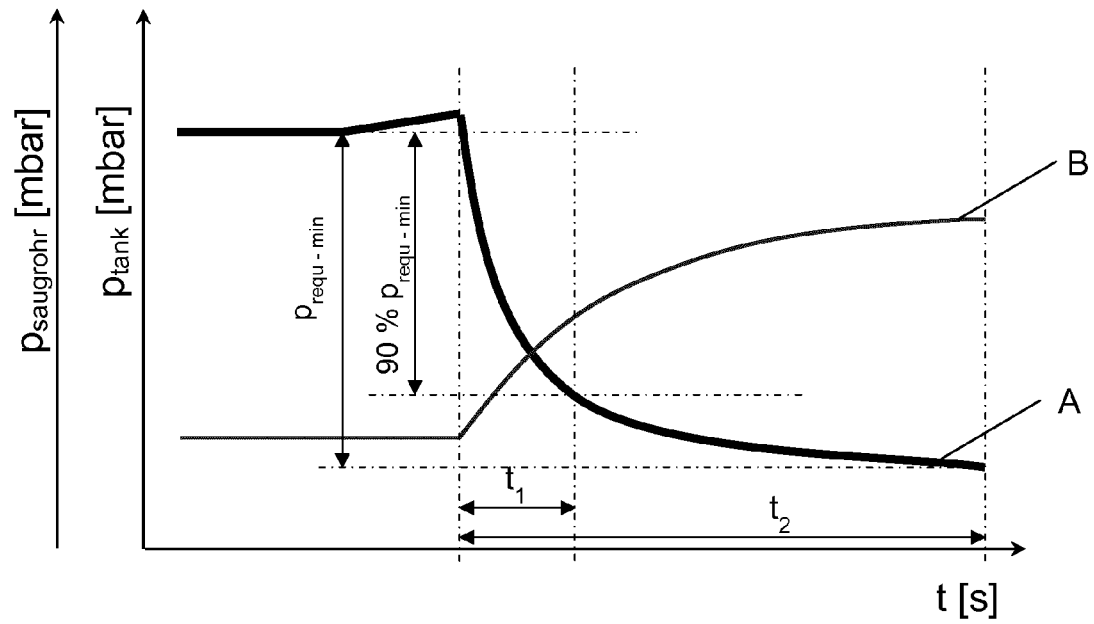
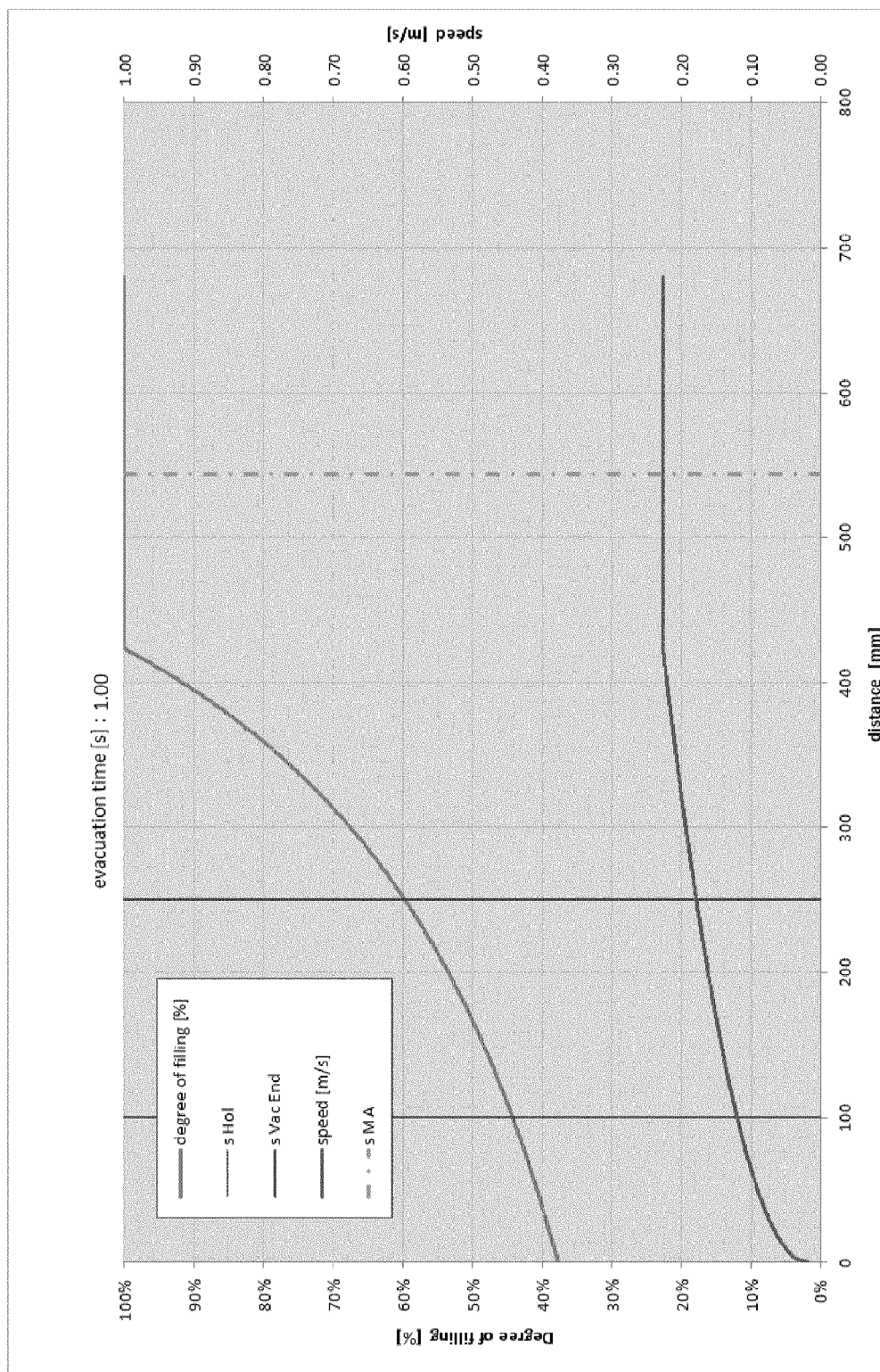


Fig. 6



METHOD FOR OPERATING A VACUUM DIE-CASTING MACHINE

[0001] The present invention relates to a method for operating a vacuum die-casting machine, with which a casting cycle can be carried out more efficiently and more rapidly.

[0002] In order to produce castings, appropriate casting material can be introduced into a casting mold having contours corresponding to the shape of the casting and can be allowed to solidify there. Die-casting machines are suitable for the production of metallic castings, such as, for example, engine blocks. A die-casting machine comprises a casting mold which consists at least of two mold halves (a fixed and a movable mold half) which together form a hollow space (also referred to as cavity or mold contour) corresponding to the component to be produced. A molten material of the material to be molded, for example aluminum, is pressed, into said hollow space under high speed and high pressure with the aid of a casting piston. After the molten metal has solidified in the hollow space, the mold is opened by movement of the movable mold half and the finished casting is ejected with the aid of ejectors.

[0003] By way of example, WO 2008/131571 A1 describes a horizontal two-plate die-casting machine. Said two-plate die-casting machine comprises a movable platen (BAP) and a fixed platen (FAP), on which one casting mold half is arranged in each case. By movement of the movable platen, the die-casting mold can be opened and closed. In the closed position, the two platens are pressed fixedly against each other such that the two casting mold halves form a closed mold. A molten metal is introduced under pressure into the closed mold and cooled by solidifying. The solidified casting can be

[0004] removed after the mold is opened (by movement of the movable platen).

[0005] For the manufacturing of automobiles, particular requirements are placed on thin- to medium-walled structural components. The latter have to have, inter alia, good weldability, high mechanical load-bearing capability and a low manufacturing scatter. In the case of a conventional die-casting method, even when the mold is well vented, there is the risk of air or gas inclusions in the molten material, which may result in undesirable porosity in the casting. Under some circumstances, the casting may therefore no longer reliably meet precisely the high requirements demanded for manufacturing automobiles.

[0006] As an alternative, certain castings, for example for manufacturing automobiles, are therefore produced in a vacuum die-casting method. The vacuum die-casting method is known to a person skilled in the art. In this case, the gas atmosphere present in the casting mold is removed at least partially, preferably as completely as possible, i.e. a negative pressure is applied. In particular for castings which have to be subjected to a subsequent heat treatment, the vacuum die-casting method has proven a preferred production method.

[0007] For carrying out the vacuum die-casting method, the die-casting machine has to be provided with powerful vacuum equipment (in particular a powerful vacuum pump and good vacuum regulation), and the mold fittings and casting fittings have to be able to be readily sealed off from the environment.

[0008] In order to carry out a vacuum die-casting method, a flow duct is provided in the casting mold, said flow duct

leading from the hollow space (also referred to as cavity or mold contour), which corresponds to the component to be produced, into a gas line which is connected to a vacuum pump. The fluidic connection between hollow space and vacuum pump can be opened and closed with the aid of a closing device, preferably a valve.

[0009] In addition, the casting chamber can be connected via an intake hole, which is arranged in the casting chamber, to a vacuum pump in order to be able to carry out the operation of evacuating the machine even more rapidly and efficiently. The fluidic connection between casting chamber and vacuum pump can be opened and closed with the aid of a closing device, preferably a valve. A corresponding vacuum die-casting machine is shown, for example, in DE 10 2004 057 324 A1.

[0010] A desired negative pressure can only be applied to the casting chamber and the mold cavity when casting chamber and mold cavity no longer have a connection to the environment. In the case of a cold-chamber die-casting machine, this is the case only when the mold is closed and the feed opening for filling the casting chamber with a molten material is sealed by the casting piston, i.e. when the casting piston in the casting chamber has reached a position in which the rest of the casting chamber and the mold cavity no longer have any connection to the feed opening.

[0011] Care should be taken in the first phase of a casting cycle to ensure that the casting piston does not exceed a certain critical speed. This is illustrated in FIG. 1. The casting piston pushes a wave of molten material therebefore when it moves within the casting chamber. At a low speed (FIG. 1a), a gas space remains in the casting chamber above the molten material, as a result of which the risk, of air inclusions rises. At excessive speeds of the casting piston (FIG. 1c), the molten material wave breaks, as a result of which air

[0012] inclusions likewise occur. At an optimum speed, what is referred to as critical speed, the wave of molten material has an optimum height (FIG. 1b), and the risk of air inclusions is minimized.

[0013] The carrying out of a casting cycle in a die-casting machine takes place on the basis of the "casting curve". The casting curve is understood as meaning the profile of the casting piston speed as a function of the casting piston travel or, after the mold filling has ended, the profile of the casting pressure as a function of the time. The casting curve is customarily divided into three phases. During the preliminary phase or first phase, the molten material is first of all built up in the casting chamber, at a comparatively low piston speed, and transported in the direction of the mold cavity. At the beginning of the mold filling phase or second phase, the casting piston is accelerated to a high speed in order to completely fill the component cavity within a very short time. At the end of the mold filling phase, the pressure rises sharply within a very short time, as a result of which the piston speed drops and the casting piston comes virtually to a standstill. This marks the beginning of the holding pressure phase or third phase, in which a high holding pressure is applied to the molten material via the casting piston.

[0014] Currently, the casting curve is still worked out empirically by the person operating the die-casting machine, in order to overcome the shortcomings associated therewith, automatization of the operation for working out the casting curve would be highly desirable.

[0015] It was the object of the present invention to provide a method for operating a vacuum die-casting machine, with which a casting cycle can be carried out more efficiently and more rapidly.

[0016] According to the present invention, measures are proposed with which a casting cycle of a vacuum die-casting machine can be carried out more efficiently and therefore more rapidly. In particular in the first phase of the casting cycle, a time saving of some seconds can be achieved with the method according to the invention, which, in the mass production of castings, leads to a considerable gain in overall time and therefore to a considerable economic advantage.

[0017] According to a first aspect of the present invention, the above object is achieved by the position of the feed opening in the casting chamber or of further openings in the casting chamber being determined in a previous learning cycle.

[0018] The present invention therefore relates to a method for ascertaining the position of at least one opening in a casting chamber of a die-casting machine, wherein a casting piston is contained in the casting chamber, comprising the following steps:

[0019] a) connecting the casting chamber or a mold cavity of a die-casting mold, which mold cavity is fluidically connected to the casting chamber, to a pump generating negative pressure or to a tank, which is brought to negative pressure with the pump, via a connecting line in a position of the casting piston in the casting chamber, in which at least a portion of the opening to be ascertained and the casting chamber can communicate with each other,

[0020] b) moving the casting piston into a position in which communication between the opening to be ascertained and the casting chamber is no longer possible, and

[0021] c) ascertaining with reference to the negative pressure in the connecting line when the casting piston, has reached the position in step b).

[0022] The positions of the openings in the casting chamber involve geometrical parameters of the die-casting machine that do not remain constant, but rather are subject to changes, for example because of a change of mold or wear. The positions of the openings in the casting chamber therefore have to be ascertained regularly.

[0023] With knowledge of the precise position of the openings in the casting chamber, the casting piston can be brought as rapidly as possible into a position in which the die-casting machine is sealed off from the environment and an effective negative pressure can be generated in the die-casting machine. Up to now, the positioning of the casting piston and the time of the generation of negative pressure in the die-casting machine took place solely by means of the operator. However, even an experienced operator requires a certain time for carrying out these steps. According to the invention, the position of the feed opening in the casting chamber and optionally also the position of further openings, such as the intake hole, are determined in a learning process. The data thus determined can be stored and taken into account when working out a casting curve for the actual casting cycle. By means of the automatization which is thus possible, a first saving on time during the casting cycle can be achieved.

[0024] The at least one opening is preferably the feed opening in a casting chamber of a cold-chamber die-casting machine.

[0025] Casting chambers of cold-chamber die-casting machines are well known. A casting piston which can be moved, preferably hydraulically, with the aid of a casting cylinder is located in the casting chamber. In the case of a vacuum die-casting machine, the casting piston is dimensioned in such a manner that it divides the casting chamber into an annular space and a piston space which are sealed off fluidically from each other.

[0026] The casting chamber is filled via a feed opening with the material to be cast. This is preferably molten metal from metals or metal alloys customarily used for die casting. However, it is also possible to use other molten materials. For example, salt cores can be produced from corresponding molten salts. The feed opening is preferably arranged in the top of the casting chamber, in the case of a horizontally arranged casting chamber.

[0027] The casting chamber of a vacuum die-casting machine is connected to the actual mold cavity. The molten material fed into the casting chamber is transferred by movement of the casting piston into the mold cavity where it solidifies and forms the actual casting. A flow duct is provided in a vacuum die-casting machine, said flow duct leading from the mold cavity into a gas line (connecting line) which is connected to a vacuum pump. The fluidic connection between hollow space and vacuum pump can therefore be undertaken by an extraction hole, wherein the connection can be opened and closed with the aid of a closing device, preferably a valve, via said extraction hole, not only can the mold cavity be evacuated, but so too can the casting chamber which is fluidically connected, to the mold cavity.

[0028] As long as the feed opening is open, the interior of the casting chamber is connected to the environment, in order to be able to generate negative pressure in the casting chamber and therefore also in the mold cavity, the feed opening has to be sealed. This can be achieved by the casting piston being moved within the casting chamber into a position in which it fluidically

[0029] decouples that part of the casting chamber which is connected to the mold cavity from the feed opening. For this purpose, the casting piston has to be moved at least into a position in which its front end facing the mold is located in the same position as that end of the feed opening which faces the mold. As soon as the casting piston has been moved into this position, an effective negative pressure can be generated in the mold cavity and the casting chamber with the aid of the vacuum pump.

[0030] According to the invention, use can be made of any vacuum pump as are conventionally used in the case of vacuum, die-casting machines, vacuum pumps of this type are known to a person skilled in the art.

[0031] According to the invention, a negative pressure, i.e. a pressure lying below the atmospheric pressure of 101,325 kPa (1.013 bar), is generated in the mold cavity and/or the casting chamber of the vacuum die-casting machine. According to the invention, preferably a negative pressure of 300 mbar to up to 50 mbar, particularly preferably of 200 mbar to up to 50 mbar and in particular preferably of 100 mbar to up to 50 mbar is generated.

[0032] It is preferred according to the invention not to connect the vacuum pump to the mold cavity and/or the casting chamber directly, but rather via a tank. This is a buffer container which can be rapidly evacuated with, a comparatively small vacuum pump and, for its part, can rapidly generate the desired negative pressure in a vacuum die-

casting machine. The tank is arranged in a connecting line between vacuum pump and die-casting machine and can be opened and closed both in relation to the vacuum pump and in relation to the die-casting machine with the aid of a closing device, preferably a valve. It is also known and possible to provide a plurality of tanks of this type between vacuum pump and mold cavity or casting chamber.

[0033] According to a preferred embodiment of the present invention, the above method for ascertaining the position of the feed opening is carried out when the die-casting mold is closed, and the connection of the casting chamber to a pump generating negative pressure is produced via an extraction hole in the die-casting mold,

[0034] According to a further preferred embodiment of the present invention, the above method for ascertaining the position of the feed opening is carried out when the die-casting mold is closed, and the connection, of the casting chamber to a pump generating negative pressure is produced via an intake opening in the casting chamber. In this embodiment, the casting chamber has a dedicated intake opening via which said casting chamber is connected to the vacuum pump. The fluidic connection between casting chamber and vacuum pump can be opened and closed with the aid of a closing device, preferably a valve. If present, said intake opening is located in a region, of the casting chamber between the feed opening and the connection of the casting chamber to the mold cavity. The intake opening is preferably arranged in the top, in the case of a horizontally arranged casting chamber.

[0035] The above method for ascertaining the position is otherwise carried out identically in both embodiments (generation of negative pressure via an extraction hole in the mold cavity or via an intake opening in the casting chamber).

[0036] In an embodiment according to the invention with an intake opening in the casting chamber, the position of the intake opening can also be ascertained with the aid of the method according to the invention. In this case, the method is carried out when the die-casting mold is open, and the connection of the casting chamber to a pump generating negative pressure or to a tank brought to negative pressure with the pump is produced via the connecting line which is connected to an intake opening in the casting chamber.

[0037] In a particularly preferred embodiment of the above method, in a first performance of steps a) to c) when the die-casting mold is closed, the position of the feed opening in a casting chamber is ascertained, as described above, and, in a second, performance of steps a) to c) when the die-casting mold, is open, the position of the intake opening in the casting chamber is ascertained by the intake opening being connected to the pump generating negative pressure or to the tank, which is brought to negative pressure with the pump, via a connecting line, the casting piston is subsequently moved into a position in which communication between the intake opening and the casting chamber is no longer possible, and it is ascertained with reference to the negative pressure in the connecting line when the casting piston has reached this position.

[0038] As described above, the intake opening is located in a region of the casting chamber between the feed opening and the connection of the casting chamber to the mold cavity. When the feed opening in the casting chamber is sealed by the casting piston and the mold cavity is closed, a

negative pressure can be generated within the mold cavity and/or the casting chamber, as described above.

[0039] If the mold is then opened, the piston space of the casting chamber also obtains contact again to the environment via its connection to the mold cavity, which is now open, and the negative pressure in the casting chamber is eliminated. It is no longer possible to generate a negative pressure in the casting chamber with the aid of a vacuum pump via the intake opening in the casting chamber.

[0040] If the casting piston is subsequently moved in the casting chamber in the direction of the intake opening, the casting piston ultimately passes into a position in which it seals the intake opening. A negative pressure now arises again in the connecting line between intake opening and vacuum pump or tank. Said negative pressure can be used for ascertaining the position of the intake opening.

[0041] The above-described method according to the invention for ascertaining the position of openings in a casting chamber is therefore carried out by ascertaining a negative pressure at a certain position of the casting piston. The position of the casting piston, at which position the negative pressure assumes a predetermined value at the measurement position, is used as being representative of the position of the corresponding opening.

[0042] According to the invention, the pressure measurement preferably takes place within the connecting lines of vacuum pump or tank to the mold cavity or casting chamber. Devices for pressure measurement are known to a person skilled in the art.

[0043] Preferably according to the invention, a gas cleaning device is located between the pump generating negative pressure or the tank and the casting chamber. The intention therewith is to prevent soiling of the vacuum pump by constituent parts of the molten material that could also be sucked up by the vacuum pump. Such gas cleaning devices, for example filters, are known to a

person skilled in the art. A gas cleaning device which is preferred according to the invention is described in European patent application No. EP 13178708,7 from the same applicant. This involves a gas cleaning device in which a tangential separator (cyclone cleaner) and a conventional filter element are arranged sequentially following one another in a device.

[0045] Preferably according to the invention, a pressure measurement takes place upstream and downstream of a gas cleaning device of this type in order to be able to identify a possible clogging of the gas cleaning device.

[0046] According to a particularly preferred embodiment of the present method of the present invention, at the beginning of the method the casting mold is closed and therefore the mold cavity is closed off from the environment. The casting piston is then moved forward in the casting chamber until the front end of said casting piston has reached approximately the center of the feed opening. The piston is now moved further forward at an adequate speed, for example in the range of 0.13 to 0.16 m/s, and the vacuum pump is activated. The vacuum pump or the tank evacuated by the latter is connected to the extraction hole in the mold cavity and/or to the intake opening of the casting chamber, depending on the variant according to the invention. The pressure in the casting chamber only drops marginally since the feed opening is still partially open. However, as soon as the front cast piston end facing the mold has reached the front feed-opening end facing the mold, the casting chamber

is sealed in relation to the environment, and the pressure in the casting chamber drops significantly. From a certain negative pressure, it can be assumed that the casting chamber is sealed in relation to the environment. The position or the front casting-piston end facing the mold is ascertained and is assumed to be representative of the position for the front feed-opening edge facing the mold.

[0047] Preferably according to the invention, use is made of the position of the front casting-piston end facing the mold, at which end the second derivative of the pressure curve (cf. FIG. 3) assumes the value of zero, i.e. a reversal point is present.

[0048] The piston can now be stopped, and the method for ascertaining the position of the feed opening can be ended.

[0049] If, in addition, an intake opening is present in the casting chamber and if the position of said intake opening is intended to be ascertained, in a second, part of the method according to the invention the mold can now be opened, and the vacuum pump switched off. The negative pressure present in the casting chamber disappears. The casting piston is moved in the casting chamber into a position in which its front end is located approximately in the center of the intake opening. The vacuum pump is activated and the pump or a tank evacuated by the latter is connected via a connecting line to the intake opening in the casting chamber. The pressure in the connecting line only drops marginally since the intake opening is still partially open. However, as soon as the front casting-piston end facing the mold has reached the front intake-opening end facing the mold, the casting chamber is sealed in relation to the vacuum pump, and the pressure in the connecting line between vacuum pump and casting chamber drops significantly. From a certain negative pressure, it can be assumed that the casting chamber is sealed in relation to the vacuum pump. The position of the front end of the casting piston is ascertained and it is assumed to be representative of the position of the

[0050] edge of the intake opening. Preferably according to the invention, use is also made here of the position of the front casting-piston end facing the mold, at which end the second derivative of the pressure curve (cf. FIG. 3) assumes the value of zero, i.e. a reversal point is present.

[0051] The position determined in this manner of the feed opening and optionally of the intake opening in the casting chamber can be used for determining a casting curve.

[0052] A casting curve for a vacuum die-casting machine according to the invention is substantially based on the speed of the casting piston in the casting chamber. As described above with reference to FIG. 1a)-c), the speed of the casting piston in the casting chamber has to be carefully selected in order to avoid undesirable air inclusions in the molten material. It is advantageous to select the speed of the casting piston in the casting chamber in such a manner that the speed corresponds as far as possible to the critical speed illustrated in FIG. 1a)-c).

[0053] The present invention therefore furthermore relates to a method for operating a vacuum die-casting machine, characterized in that a casting curve for carrying out a casting cycle on the basis of predetermined and/or experimentally ascertained characteristic values of the die-casting machine is determined with the aid of a computer program product for operating the die-casting machine.

[0054] According to the invention, a casting curve for carrying out a casting cycle is proposed to the operator of the

die-casting machine, with the aid of which casting curve the casting cycle can be carried out more rapidly, especially in the first phase of the casting cycle. Said casting curve is determined by a computer program product with which the die-casting machine is operated.

[0055] Computer program products for operating die-casting machines are known. The applicant's program Dat@net is mentioned by way of example. Die-casting machines have corresponding components, such as processors and memory modules with the aid of which a computer program product can be operated. Via an interface, for example a monitor, and an associated input medium, such as a keyboard, mouse or touchscreen, the die-casting machine can be operated by an operator with the aid of the computer program product.

[0056] The computer program product determines a casting curve on the basis of predetermined and/or experimentally ascertained characteristic values of the die-casting machine. Said characteristic values change, for example, depending on the die-casting mold used or due to wear and therefore have to be regularly adapted or newly ascertained.

[0057] The characteristic values for determining the casting curve can be input manually into the computer program product. However, preferably according to the invention, said characteristic values are at least partially determined previously experimentally and the experimental data obtained are transmitted directly to the computer program product.

[0058] It has been shown that, in the case of a vacuum die-casting machine, the evacuation time, i.e. the time required until a predetermined negative pressure is reached, is a substantial factor. With a decrease in gas volume in the casting chamber, the risk of gas inclusions in the molten material drops and the casting piston can correspondingly be moved more rapidly.

[0059] As explained above, a desired negative pressure in a casting chamber and the closed mold cavity associated therewith can only be generated when the casting chamber is sealed in relation to the environment, i.e. the feed opening in the casting chamber is closed by the casting piston.

[0060] According to an embodiment according to the invention, in order to determine a casting curve, a learning cycle is carried out in advance, in which the evacuation time, i.e. the time until a predetermined negative pressure is reached in the mold cavity, is determined experimentally.

[0061] According to a preferred embodiment of the present invention, said learning cycle is carried out taking into consideration the position of the feed opening and optionally of the intake opening in the casting chamber, which positions have been ascertained, by the method described above. This permits a more rapid and more efficient procedure.

[0062] In order to carry out the learning cycle, the die-casting mold is closed, and the casting piston is moved, within the casting chamber into a position in which the front casting-piston end facing the mold is located approximately level with the center of the feed opening. The casting chamber is now connected, either directly via an intake opening of the casting chamber or indirectly via an intake hole in the mold cavity connected, to the casting chamber, to the vacuum pump or to a tank evacuated by the vacuum pump. The casting piston is moved, as previously described, into a position in which it seals the casting chamber in relation to the environment by closing the feed opening. The time until the negative pressure in the

[0063] casting chamber reaches a predetermined value is now ascertained.

[0064] Preferably according to the invention, the time taken until a negative pressure corresponding to 90% of the predetermined negative pressure is reached in the mold cavity and the time taken until a negative pressure corresponding to 100% of the predetermined negative pressure is reached in the mold cavity are ascertained. This permits a more precise ascertaining of the operability of the vacuum system of the die-casting machine.

[0065] Preferably, in a first step of the learning cycle, the negative pressure in the connecting line connected to the vacuum pump or to an evacuated tank is ascertained before said connecting line is fluidically connected to the casting chamber and/or to the mold cavity. In order to reach a desired negative pressure in the casting chamber and/or in the mold cavity, the appropriate negative pressure has to be present in the connecting line. Should the negative pressure, which is determined, in the first step of the learning cycle, in the connecting line lie above the negative pressure which is intended to be reached subsequently in the casting chamber and/or the mold cavity, the learning cycle is broken off and an error analysis should be carried out (for example a search for a leakage in the apparatus or for a plugged gas cleaning device).

[0066] In the event of adequate negative pressure in the connecting line, the learning cycle, as described above, is carried out. With the learning cycle, not only can the evacuation time be ascertained here, as described above, but so too can the overall state of the vacuum system. For the efficient carrying out of a vacuum die-casting process, a predetermined negative pressure has to be able to be reached within a predetermined time, for example a negative pressure of 100 mbar within 3 s from sealing of the casting chamber from the environment. Should said predetermined values not be reached within the learning cycle, an error analysis should be carried out before the actual die-casting process is initiated.

[0067] If, according to a preferred embodiment of the present invention, the time until a negative pressure corresponding to 90% of the predetermined negative pressure in the mold cavity is reached is additionally ascertained, the value thus determined can be used for evaluating the suction capability of the vacuum device of the die-casting machine.

[0068] Preferably according to the invention, the time until a predetermined negative pressure is reached in the mold cavity is checked at regular intervals in order to identify leaks which may occur or a clogging of a gas cleaning device.

[0069] According to the invention, the casting curve is additionally determined as a function of the degree of filling of the casting chamber. The degree of filling in the casting chamber, i.e. the quantity of molten material in the casting chamber in relation to the maximum quantity of molten material to be fed into the casting chamber, is a substantial factor for the behavior of the molten material in the casting chamber, as shown in FIG. 1.

[0070] Preferably according to the invention, the computer program product determines the casting curve of a cold-chamber die-casting machine as a function of the evacuation time determined in the learning cycle and as a function of a predetermined degree of filling. Preferably according to the invention, a degree of filling of the casting chamber of 20 to 50%, preferably 30 to 40%, is used with respect to a casting

chamber with a casting piston in the starting position (i.e. in the position as far away as possible from the mold).

[0071] Preferably according to the invention, further geometrical characteristic data of the die-casting machine are used by the computer program product for determining the casting curve. In particular, the positions of feed opening and intake opening in the casting chamber, which positions are determined in the position ascertaining method previously, are taken into consideration in order to set the speed of the casting piston and the process of the evacuation of the casting chamber and of the mold cavity as optimally as possible.

[0072] According to a preferred embodiment of the present invention, the speed of the casting piston is determined at a position in which its front end has reached that edge of the intake opening in the casting chamber which faces the mold. According to the invention, this speed is determined as a function of the reciprocal value of the degree of filling of the casting chamber and is taken into consideration in the calculation of the other points of the casting curve.

[0073] As further geometrical characteristic data, for example the diameter of the casting piston, the active length of the casting chamber (i.e. the casting-chamber length available for the casting process), the weight of the casting to be produced (with and without a gate), the density of the casting and the density factor of liquid/solid of the molten material used can be taken into consideration in the computer program product.

[0074] The casting curve is therefore determined case-specifically with the aid of a computer program product on the basis of predetermined and/or previously ascertained characteristic data. A person skilled in the art can undertake the required modification of a computer program product conventionally used in vacuum die-casting machines on the basis of his expert knowledge and can optionally adapt same if the casting curve determined by the computer program product does not supply any optimum and/or desired results during the die-casting process.

[0075] With the aid of the present invention, it is possible to carry out the casting cycle, in particular the first phase of the casting cycle, more rapidly and more efficiently. Customarily, a time saving of 1 to 10 s, preferably 2 to 5 s, can be achieved per casting cycle. This results in a considerable economic advantage in the production of castings in large piece numbers.

[0076] The present invention furthermore relates to a computer program product for operating a vacuum die-casting machine, wherein the software product executes the step of determining a casting curve for carrying out a casting cycle on the basis of predetermined and/or experimentally ascertained characteristic values of the die-casting machine.

[0077] Computer program products for operating die-casting machines are known. The applicant's program, Dat@nef is mentioned by way of example. The computer program product, according to the invention preferably corresponds to such a known computer program product and has been modified to the effect that it can execute the above-described step according to the invention of determining a casting curve. A person skilled in the art can undertake the required modification of a computer program product conventionally used in vacuum die-casting machines on the basis of his expert knowledge and can optionally adapt same if the

casting curve determined by the computer program product does not supply any optimum and/or desired results during the die-casting process.

[0078] The present invention is explained in more detail below with reference to non-limiting examples and figures, in which:

[0079] FIGS. 1a-c: show the above-explained relationship between the speed of the casting piston in the casting chamber and the shape of the wave of molten material moved by the casting piston,

[0080] FIG. 2: shows a schematic illustration of an embodiment of a die-casting machine according to the invention,

[0081] FIG. 3: shows a schematic illustration of an embodiment of the vacuum arrangement of a die-casting machine according to the invention,

[0082] FIG. 4: shows a schematic illustration of an embodiment of the method according to the invention for ascertaining the position of the feed opening and of the intake opening,

[0083] FIG. 5: shows an explanation of the evacuation times t_1 and t_2 which are determined in a learning process,

[0084] FIG. 6: shows an example of a casting curve determined according to the invention.

[0085] The conditions, which are shown in FIG. 1, within a casting chamber, which is filled with molten material, as a function of the speed of the casting piston have already been explained above. The casting piston pushes a wave of molten material therebefore when it moves within the casting chamber. At a low speed (FIG. 1a), a gas space remains above the molten material in the casting chamber, as a result of which the risk of air inclusions rises. At excessive speeds of the casting piston (FIG. 1c), the molten material wave breaks, as a result of which air inclusions likewise occur. At an optimum speed, what is referred to as critical speed, the wave of molten material has an optimum height (FIG. 1b), and the risk of air inclusions is minimized.

[0086] FIG. 2 shows a schematic illustration of an embodiment of a die-casting machine 1 according to the invention. This is a cold-chamber vacuum die-casting machine. The die-casting machine 1 comprises a movable platen 2 with a mold half 4 arranged thereon, and a fixed platen 3 with a mold half 5 arranged thereon. In the closed state, the mold halves 4 and 5 form the mold cavity 11 which corresponds to the shape of the casting to be produced.

[0087] The die-casting machine 1 according to FIG. 2 furthermore has a casting chamber 6 which extends through the fixed platen 3 and the mold half 5 as far as the mold cavity 11 and is fluidically connected to the mold cavity 11. The casting piston 7 is arranged movably in the casting chamber 6. The casting piston 7 has a front end 7a and is connected to a casting cylinder (not shown) via the casting rod 8.

[0088] A feed opening 9 for filling the casting chamber 6 with molten material, and an intake opening 10 for connecting the casting chamber 6 to a vacuum pump 17 are arranged in the top of the casting chamber 6,

[0089] The mold cavity 11 is fluidically connected to the vacuum pump 17 via a flow line 12 and a valve 13 (referred to as chill-vent). The intake opening 10 and the flow line 12 are connected to a tank 16 via lines 14 and 15. The tank 16 can be evacuated via the vacuum pump and, for its part, can generate a desired negative pressure in the casting chamber

6 or the mold cavity 11. This arrangement has the advantage that a comparatively large volume can be brought to the desired negative pressure in the tank 16 with a comparatively small, vacuum pump. Said tank volume can be used to generate a desired negative pressure in the casting chamber 6 or in the mold cavity 11 within a short time interval. As a result, the time during the casting cycle can be used in order to reproduce the desired negative pressure in the tank 16 with the vacuum pump 17 in order, if the need arises, to be able to reset, a desired negative pressure in the casting chamber 6 or the mold cavity 11.

[0090] Pressure measurement devices 18 and 19 are arranged in the connecting lines 14 and 15.

[0091] FIG. 3 shows a schematic illustration of an embodiment of the vacuum arrangement of a die-casting machine according to the invention, wherein, the same reference signs denote identical elements in FIGS. 1 and 2.

[0092] The casting chamber 6 comprises an intake opening 10 which is connected via a connecting line 15 to a tank 16 which can be evacuated by a vacuum pump 17. A gas cleaning device 20 is arranged in the connecting line 15. The gas cleaning device is preferably a device as described in European patent application No. EP 13173706.7 of the same applicant. A gas cleaning device is involved here in which a tangential separator (cyclone cleaner) and a conventional filter element are arranged following one another sequentially in a device.

[0093] Pressure measurement devices 19 which can be decoupled from the connecting line 15 via valves 21 are arranged upstream and downstream of the gas cleaning device 20. The pressure in the connecting line 15 and therefore in the casting chamber 6 can be determined with the pressure measurement devices 19. In addition, it can be checked with the pressure measurement devices 19 whether the gas cleaning device 19 is operable or, for example, is plugged.

[0094] The casting chamber 6 can be decoupled from the tank 16 and the vacuum pump 17 with the aid of a valve 22.

[0095] The mold cavity 11 is connected via a flow duct 12 and a connecting line 14 to the tank 16 which can be evacuated by a vacuum pump 17. A gas cleaning device 20a is also arranged in the connecting line 14. The gas cleaning device is preferably a device as described in European patent application No. EP 13178708.7 of the same applicant. A gas cleaning device is involved here, in which a tangential separator (cyclone cleaner) and a conventional filter element are arranged following one another sequentially in a device.

[0096] A pressure measurement device 19 which can be decoupled from the connecting line 14 via a valve 21 is arranged upstream of the gas cleaning device 20a. The pressure in the connecting line 14 and therefore in the mold cavity 11 can be determined with the pressure measurement device 19.

[0097] The vacuum cavity 11 can be decoupled from the tank 16 and the vacuum pump 17 with the aid of a valve 23.

[0098] A hydraulic closing unit 24, which can be decoupled via a valve 25, can optionally be connected to the system, as shown in FIG. 3.

[0099] FIG. 4 shows a schematic illustration of an embodiment of the method according to the invention for ascertaining the position of the feed opening and of the intake opening. FIG. 4 shows the pressure profile as a function of the position of the casting piston during the carrying out of the method according to the invention.

[0100] At the beginning of the method according to the invention, the casting piston 7 is located in the casting chamber 6 in a position $S_{i,0}$ in which the feed opening 9 in the casting chamber 6 is not sealed and is located in the piston space of the casting piston 7. The two mold halves 4 and 5 are closed by movement of the movable platen 2 into the closed position, and therefore the mold cavity is sealed in relation to the environment. At this time, normal pressure (approximately 1000 mbar) prevails in the casting chamber 6 since the casting chamber 6 is in contact with the environment via the feed opening 3.

[0101] The casting piston 7 is now moved in the casting chamber 6 into a position in which its front end 7a is located approximately level with the middle of the feed opening 9 (position “vacuum start”). The valve 13 to the mold cavity 11 is closed and the valve 22 to the intake opening 10 is opened. Alternatively, it is also possible for the valve 22 to the intake opening 10 to be closed and the valve 13 to the mold cavity 11 to be opened. A slight drop in pressure Δp_n occurs in the casting chamber 6. The casting piston 7 is now moved in the casting chamber 6 until the front end 7a of said casting piston reaches that edge of the feed opening 9 which faces the mold. This position is referred to as $s_{hol, fin}$. From said position $s_{hol, fin}$ of the casting piston 7, the casting chamber 6 is sealed in relation to the environment, and a significant drop in pressure occurs. The casting piston is moved somewhat further as far as a position at which the pressure profile has a reversal point, i.e. the second derivative of the p-S curve assumes the value 0. This position is referred to as $s_{ph, eff}$ and is considered to be representative of the position of the feed opening 9 (more precisely of the edge thereof facing the mold).

[0102] In the embodiment according to FIG. 4, the casting piston 7 is now stopped and the evacuation of the casting chamber 6 ended. The tank 16 is evacuated to the desired value with the vacuum pump 17, and the mold halves 4 and 5 are opened from each other by movement of the movable platen 2 into an open position (position “vacuum stop 1”). The mold cavity 11 thereby obtains contact with the environment, and the pressure in the casting chamber 6 connected to the mold cavity 11 rises again to normal pressure. The casting piston 7 is now moved in the casting chamber 6 into a position in which the front end 7a of said casting piston is located approximately level with the middle of the intake opening 10 (position “vacuum stop 2”). The valve 13 to the mold cavity 11 is closed and the valve 22 to the intake opening 10 is opened. A slight drop in pressure Δp_n occurs in the casting chamber 6. The casting piston 7 is now moved in the casting chamber 6 until the front end 7a of said casting piston reaches that edge of the intake opening 10 which faces the mold. This position is referred to as $s_{Saugloch, fin}$. From said position $s_{Saugloch, fin}$ of the casting piston 7, the casting chamber 6 is sealed in relation to the intake opening 10, and a significant drop in pressure occurs in the connecting line 15. The casting piston is moved somewhat further as far as a position at which the pressure profile has a reversal point, i.e. the second derivative of the p-S curve assumes the value 0. This position is referred to as $s_{eh, eff2}$ and is considered to be representative of the position of the intake opening 10 (more precisely of the edge thereof facing the mold).

[0103] In the embodiment according to FIG. 4, the evacuation of the connecting line 15 is now ended. If the casting piston 7 is now moved forward further in the casting

chamber 6, it releases the intake opening 10 from the position “vacuum stop 2”. As a result, the connecting line 15 comes into contact with the casting chamber 6 and the mold cavity 11, which are in contact with the environment. The pressure in the connecting line 15 thereby rises again to approximately normal pressure. FIG. 5 explains the evacuation times t1 and t2 which are determined during a learning cycle of an embodiment according to the invention of the present invention. The period of time t1 corresponds to the period of time in which the pressure profile (indicated by the curve A shown in bold) in the connecting line 14 or 15 between casting chamber 6 or mold cavity 11 and tank 16, which is evacuated by the vacuum pump 17, corresponds to a drop in pressure from, normal pressure to a value which corresponds by 90% to the predetermined negative pressure to be reached. The period of time t2 corresponds to the period of time in which the pressure profile indicated by the curve A shown in bold) in the connecting line 15, 15 between casting chamber 6 or mold cavity 11 and tank 16, which is evacuated by the vacuum pump 17, corresponds to a drop in pressure from the value reached after the period of time t1 to the predetermined negative pressure to be achieved. The curve B, which is shown by a thin line, corresponds to the parallel pressure profile in the tank 10. The pressure rises there by absorption of gas from the casting chamber 6 or the mold cavity 11. Prior to the next evacuation, the tank 16 has to be brought again to the corresponding negative pressure.

[0104] FIG. 6 shows an example of a casting curve according to the invention. The profile of the speed of the casting piston 7 is illustrated as a function of the piston travel, and the change in the degree of filling of the casting chamber 6 is shown as a function of the movement of the casting piston 7. The speed profile of the casting piston 7 is determined by the computer program product, as described above, and indicated to the user. In the case of the casting curve shown here, the casting piston 7 is overproportionally accelerated, so that where $s=100$ mm as far as the mold-side end of the feed opening 3. The speed of the casting piston 6 is subsequently increased substantially proportionally to the distance covered (constant acceleration) until, when a degree of filling of 100% is reached in the casting chamber 6, the casting piston 7 is no longer accelerated, but rather the casting piston 7 is moved further in the casting chamber 6 at a constant speed.

1-15. (canceled)

16. A method for ascertaining a position of at least one opening in a casting chamber of a die-casting machine, wherein a casting piston is contained in the casting chamber, the method comprising:

- connecting the casting chamber or a mold cavity of a die-casting mold, which mold cavity is fluidically connected to the casting chamber, to a pump generating negative pressure or to a tank, which is brought to negative pressure with the pump, via a connecting line in a position of the casting piston in the casting chamber, in which at least a portion of the opening to be ascertained and the casting chamber can communicate with each other,
- moving the casting piston into a position in which communication, between the opening to be ascertained and the casting chamber, is no longer possible, and
- ascertaining with reference to the negative pressure in the connecting line when the casting piston has reached the position in step b).

17. The method as claimed in claim **18**, wherein the at least one opening is a feed opening of the casting chamber of a cold-chamber die-casting machine.

18. The method as claimed in claim **17**, wherein the method is carried out when the die-casting mold is dosed, and the connection to the pump generating negative pressure or to the tank, which is brought to negative pressure with the pump, is produced via the connecting line which is connected to an extraction hole of the die-casting mold.

19. The method as claimed in claim **17**, wherein the method is carried out when the die-casting mold is closed, and the connection of the casting chamber to the pump generating negative pressure or to the tank, which is brought to negative pressure with the pump, is produced via the connecting line which is connected to an intake opening in the casting chamber.

20. The method as claimed in claim **16**, wherein the at least one opening is an intake opening in the casting chamber of a cold-chamber die-casting machine,

21. The method as claimed in claim **20**, wherein the method is carried out when the die-casting mold is open, and the connection of the casting chamber to the pump generating negative pressure or to the tank, which is brought to negative pressure with the pump, is produced via the connecting line which is connected to the intake opening in the casting chamber.

22. The method as claimed in claim **18**, wherein, during a first performance of steps a) to c) when the die-casting mold is closed, the position of a feed opening in the casting chamber is ascertained, and, during a second performance of steps a) to c) when the die-casting mold is open, the position of an intake opening in the casting chamber is ascertained by the intake opening which is connected to the pump generating negative pressure or to the tank, which is brought to negative pressure with the pump, via the connecting line, the casting piston is subsequently moved into the position in which communication between the intake opening and the casting chamber is no longer possible, and it is ascertained with reference to the negative pressure in the connecting line when the casting piston has reached this position,

23. The method as claimed in claim **18**, wherein a gas cleaning device is located between the pump generating negative pressure or the tank and the casting chamber or the die-casting mold.

24. A method of operating a vacuum die-casting machine, wherein a casting curve for carrying out a casting cycle on a basis of predetermined and/or experimentally ascertained characteristic values of the die-casting machine is determined with the aid of a computer program product for operating the die-casting machine.

25. The method as claimed in claim **24**, wherein the experimentally ascertained characteristic values of the die-casting machine involve a time taken until a predetermined negative pressure is reached in a mold cavity,

28. The method as claimed in claim **25**, wherein a time taken until a negative pressure corresponding to 90% of the predetermined negative pressure is reached in the mold cavity and the time taken until a negative pressure corresponding to 100% of the predetermined negative pressure is reached in the mold cavity are ascertained.

27. The method as claimed in claim **24**, wherein the predetermined characteristic values of the die-casting machine involve the position of the feed opening and/or of the intake opening in the casting chamber.

28. The method as claimed in claim **24**, wherein the time taken until a predetermined negative pressure is reached in the mold cavity is checked at regular intervals in order to identify any leak which may occur.

29. The method as claimed in claim **24**, wherein the casting curve is additionally determined as a function of a degree of filling of the casting chamber.

30. A computer program product for operating a vacuum die-casting machine, wherein the software product executes the step of determining a casting curve for carrying out a casting cycle on the basis of predetermined and/or experimentally ascertained characteristic values of the die-casting machine.

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