Weight control of the metal dosage in die-casting

by Hans-Peter Braunger and Rudolf Hann

Die-casting is a very effective way of mass-producing cast metal parts and the method is widely used in the automobile industry. Liquid metal is passed from a furnace to a casting machine where it is formed in a mold under pressure. It is important that the correct quantity of material is used as this directly affects the product quality, but there are a number of variables influencing the dosage which must be automatically controlled. This article describes the design of a dosage controller which includes measurement of the level of liquid metal in the furnace. The level is obtained indirectly by weighing the furnace and its contents using HBM weighing equipment.

Introduction

In die-casting liquid metal is passed into a metal casting mold under a high pressure of up to 1000 bar (14500 psi) and with speeds of up to 7 m/s (23 ft/s). Castings are produced in rapid sequence with exact dimensions and having a Very smooth, clean surface. Normally die-castings only require a slight amount of further processing and usually this is limited to mating surfaces.

Die-casting machines, similar to that shown in **Fig. 1**, are used for the production of die-castings. This type of machine consists mainly of a mold support holding the die-casting mold, together with the closing and casting systems, usually hydraulic controlled, which bring the mold halves together and apply the liquid metal.

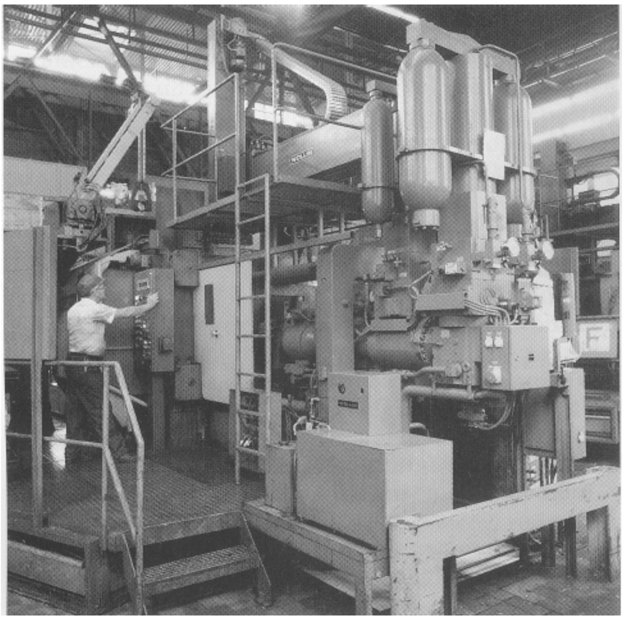

Fig. 1: Die-casting machine

The metal to be cast, which in this application is an aluminum-based alloy, is kept in the liquid state in a holding furnace from where a precise dose is passed into the pressure chamber of the casting system. The metal can be taken from the oven using ladling equipment which dips into the metal bath and transfers a defined quantity of metal to the machine. With the equipment used in this application, the metal is passed directly to the die-casting machine through a siphon by air pressure produced in an enclosed furnace section.

Within the die-casting machine a piston forces the shot of liquid metal for each casting sequence from the pressure chamber into the mold. Depending on the cast

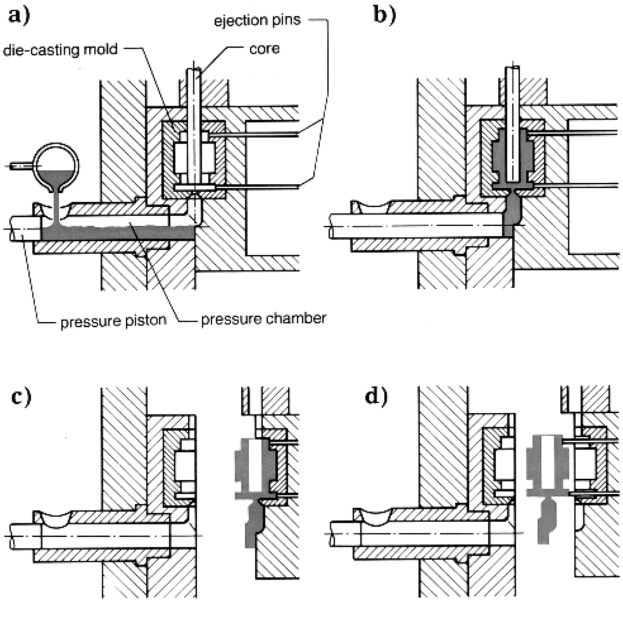

Fig. 2: Main steps in a die-casting process

a) dosing **b) closing**
c) opening **d) ejection**

part and on the degree of automation from 30 to 180 castings per hour can be produced. The metal solidifies in the mold, which, when opened, reveals the casting with its sprue where the metal was fed into the mold. The die-casting process is shown diagrammatically in **Fig. 2**.

The butt, or slug as it is also called, is part of the gating system. **Figure 3** shows a die-casting with the sprue of the gating system and the butt. Variations in the length of butt from shot to shot are unavoidable, but the uniformity in butt length is still an important criterion in assessing how well the metal dosing system is working. Too much or too little metal leads to waste, defects in the casting and to an increased proportion of remelted castings. Modern die-casting machines and machine controllers therefore require that the quantities of metal fed to the machine are as constant as possible.

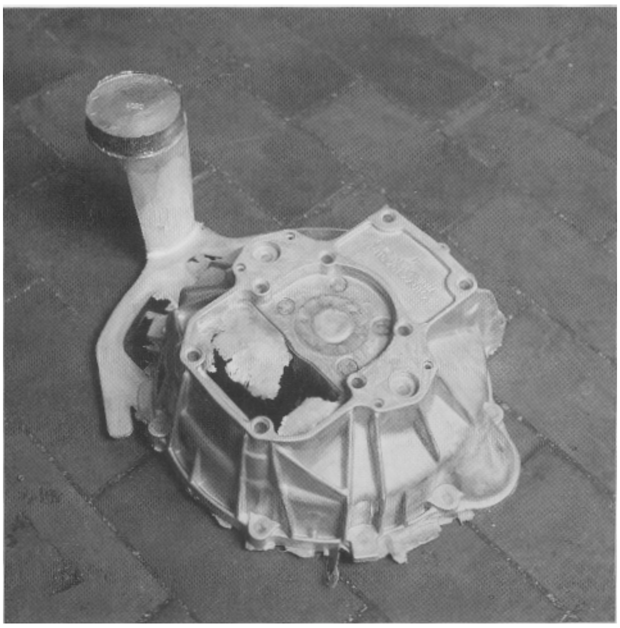

Fig. 3: Die-cast part with gating sprue and butt

Furnace control methods

The type of furnace control previously used was not regarded as the optimum. All the possible ways of improving the casting results, including changes in organization and modifications to the existing equipment, had been tried. Therefore, there was an urgent need for a new method of furnace control.

Extensive preliminary tests and detailed examinations were carried out on air pressurized single and double chamber induction furnaces in the quest for a new furnace control. Twenty-one furnaces were analyzed and these can be subdivided into four groups, as shown in **Fig. 4**, depending on the method of operation and type of control:

a) *Double chamber furnace without automatic butt control* **(Fig. 4a)**.

The casting time is manually set by the operator through the air pressure acting on the metal surf ace and the pressure is adjusted as required. The weight of the casting and the level of metal in the furnace are the main factors affecting the casting time.

b) *Enclosed, airtight single chamber furnace with a time allowance per shot and automatic butt control* **(Fig. 4b)**.

In this case a basic dosage time period is set by an electronic casting time relay. Then, depending on the falling level in the metal bath, the dosage time is extended by an adjustable period after each shot using a motor-driven potentiometer. In addition, the butt control signal, which is obtained by the interrogation of two limit switches, is mixed with the potentiometer signal.

c) *Single chamber furnace on mechanical weighing equipment with automatic butt control* **(Fig. 4c)**.

The amount of liquid metal present in the bath is obtained using a mechanical weighing machine. Corrections to the casting time, precompression and supplementary pressure are made in response to the length of butt, furnace level and settings made by the operator.

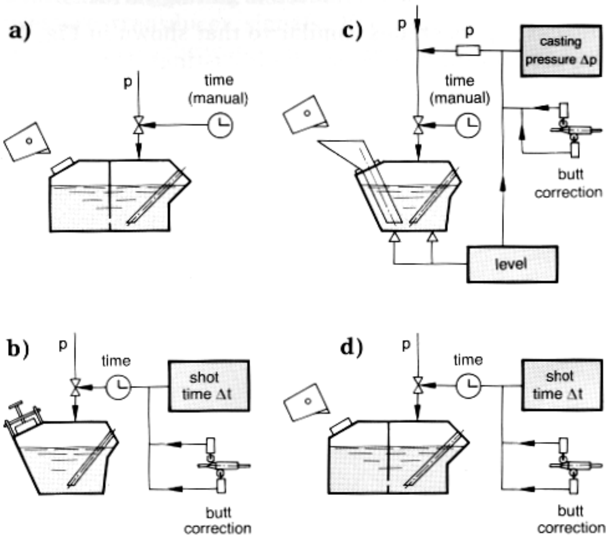

Fig. 4: Various furnace designs for die-casting machines

a) double chamber furnace without automatic butt control
b) enclosed airtight single chamber furnace with increase in time per shot and automatic butt correction
c) single chamber furnace placed on a mechanical weighing machine and with automatic butt correction
d) double chamber furnace with increase in time per shot and automatic butt correction

d) *Double chamber furnace with increased time per shot and automatic butt control* **(Fig. 4d)**.

In principle this method works in the same way as b), but it does not use a closable lid.

As stated at the beginning, none of these above mentioned systems could fulfill the demanded requirements. The preliminary tests soon showed that the dosing must be a function of the level in the furnace. The level is the only relevant quantity when subjecting the metal in the bath to air pressure during dosing; it does not matter whether a constant pressure is used for a computed time or a computed pressure applied for a permanently set time period. Controllers which extend the dosage time by a fixed amount after each shot cannot produce satisfactory results; likewise, controllers which compute the casting time only based on the length of the butt are also unsuitable. This method was not implemented, because pressure control at the required pressures of about 60 mbar to 160 mbar (0.87 psi to 2.32 psi) and with such large volumes are extremely difficult.

Planning a new dosage controller

The requirements for a new dosage controller resulted from the considerations outlined above. The process should be fully automatic which means that with any level in the bath, the dosage period is automatically computed without manual intervention. This is an important prerequisite for multi-machine operation. The computation of the dosage period is made at constant pressure using a level measurement. The pressure acting on the surf ace of the bath is produced with a high pressure fan. The furnace must be able to be filled at any time irrespective of the current level. A dosage uncertainty of < ± 150 g is required and it should be possible to reproducibly set the operating parameters based on the weight of the part in order to be able to set up the system quickly following a change in the type of casting. Other requirements expected from the new system are those relating to operational safety, as well as simple operation, easy maintenance and modular construction of the electronic system. The inclusion of suitable safety shut-down devices was regarded as an important feature of the specification.

Various methods of measuring the level in the furnace were considered. For example, one method would be to probe the surface of the bath with two metal rods. These would be lowered until electrical continuity was found on touching the bath's surface. Ceramic probes, which find the level using embedded inductive windings, were also investigated. Both methods are relatively unreliable and inaccurate. As a result of corrosion in the aluminum bath, the two metal rods must be renewed regularly. At the time of the investigation the ceramic probe was still not reliable in operation. There is also the risk of caking with slag, leading to incorrect measurements. Likewise, probing the bath surface with ultrasonic or infrared sensors was shown to be inadequate in early tests due to slag covering the surface.

Another way of defining the level is to weigh the complete furnace. Suitable measurement transducers for this purpose are primarily load cells operating on the strain gage principle. Before using them on the furnace there were three important questions to be answered: it had to be ascertained to what extent the furnace inductors would affect the measurement characteristics of the load cells and how hot the load cells would become which were to be mounted directly on the furnace. The third question concerned the accuracy to which the weight of the furnace and its contents could be measured.

Answers to the first two points could be found through testing. The electrical effects on a load cell are negligible. The 50 Hz inductor frequency appears to be completely filtered out in the measuring amplifier. The temperature of the load cells in the immediate vicinity of an inductor was only 50°C (122°F), i.e. significantly less than the manufacturer's permissible temperature of 85°C (185°F).

The weighing accuracy could not be proved by testing, but instead only a theoretical error assessment was applied. The manufacturer's data states that the load cells have a maximum combined error of ± 0.02 %. This relatively small error is however too large for the dosage time to be determined directly from the load signal. Despite this, weighing provides the most accurate and convenient method of determining the level in the bath. This is explained in more detail below.

If the furnace is refilled, then the controller resets the cumulative correction time due to the interrogation of the butt length to zero. Each first shot is therefore dosed only with the base time and the correction time relating to the level. Then the point in time at which the furnace is filled and the quantity of metal loaded into the furnace are immaterial.

Design of a new dosage control

Since the dosage time cannot be set directly proportional to the load signal on account of the measurement uncertainty being too large, an indirect way must be used. It was found in preliminary testing that the dosage time only had to be extended by about 15 % between the operating states "Furnace full" and "Furnace empty", i. e. during the consumption of about 300 kg of usable furnace content. This fact gave rise to the specification of a base time for each part to be cast, relating to its weight. An appropriate correction time could then be added to this period depending on the level. Then the error in weighing does not affect the total dosage time, but just the correction time which represents only a maximum of 15 % of the total dosage time.

Through the use of a fixed base time and a correction time referred to the level in the bath, a linear relationship between the level and the total dosage time is produced. However, this linearity results in a dosage quantity that is too low for the last few shots of the useful furnace content. Therefore, without automatic feedback between the butt length and the control of dosage time, the time period formed by the sum of the base and correction times is not accurate enough and butts of incorrect length are produced. As a consequence, feedback of the butt length to the dosage control must be provided. As with earlier controllers, this is implemented by the interrogation of the butt length using two limit switches which give a result in the form "too short", "O.K." or "too long". The controller then extends or reduces the dosage time by an adjustable time period as required for the following shot.

Where there is a non-linear relationship between the level and the total dosage time, the controller can also provide a method of matching the time to the requirements by using a correction curve instead of extending the time linearly with the reduction in bath weight. This may be necessary where the furnace lining is worn in places or where the level in the furnace has fallen considerably. This feature is however not included here. The dosage control process is summarized below:

- the level of the bath is interrogated by weighing shortly before the start of the dosage process;
- the required correction time is computed depending on the level using a correction factor and it is then added to a fixed base time;
- the dosage is initiated by the machine controller and the compressed air valve in the furnace remains open as long as required by the dosage control;
- after the shot has been produced, two limit switches on the die-casting machine's piston rod acquire the butt length. If required, the dosage time of the following shot is changed by a preset amount.

Construction of the dosage controller

The furnace to be weighed is supported at three points, each with a load cell of type C3H2 having a nominal load of 5t (4.92 tons). The load cells have a measurement uncertainty of 0.03%, i.e. their largest single error is smaller than 0.03%. The three load cells are wired in parallel and the common output therefore represents the average of the three separate signals. The load cells are mounted on ball-bearings in order to prevent lateral forces, which may arise for example with the expansion of the container under varying temperature conditions, from affecting the transducer. Pendle supports transfer the force into the load cells. The container is held on the load cells by four horizontally mounted stay rods with knuckle eyes. **Figure 5** shows one of the three installed load cells and one of the stay rod anchorage points. All pipe joints and other furnace connections in the loading direction are mounted using a flexible method in order to avoid force shunts. The weighing equipment is protected against mechanical damage by protective devices which can even withstand ramming by fork-lift trucks.

The signal from the load cells is passed to an MG 3150B 225 Hz Carrier Frequency Measuring Amplifier. The amplifier's taring system electronically suppresses the approximately 6 t (5.9 tons) tare weight of the furnace and its measurement range is set to 1000 kg (2204 lb). This means that with a net load on the load cells of 1000 kg, an output signal of 10 V is produced. The working range of the furnace lies between the filling levels of 600 kg (1322 lb) and 300 kg (661 lb). Within this range the dosage for each shot is made in steps of 12 kg ± 0.15 kg (26.5 lb ± 0.33 lb). The system is calibrated at 600 kg (1322 lb). A DA 24 Digital Indicator is connected to the measuring amplifier. With its channel selector switch in the position "Furnace weight", the indicator displays the weight of the furnace content (amplifier output signal). The level in the furnace is monitored by limit switches controlling an illuminated strip with five segments which acts as a level indicator. This strip which is shown in **Fig. 6** can be read, even at a

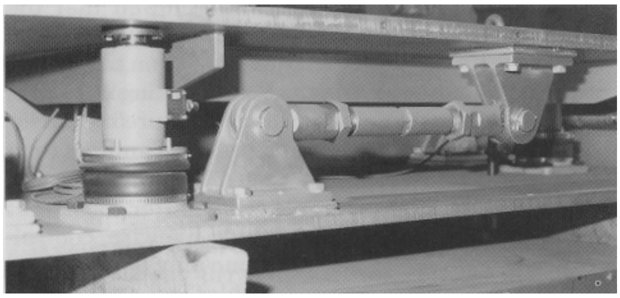

Fig. 5: One of the three load cells with its ball-bearing forming a support for the furnace; anchorage of the furnace is provided by a stay rod with knuckle eyes

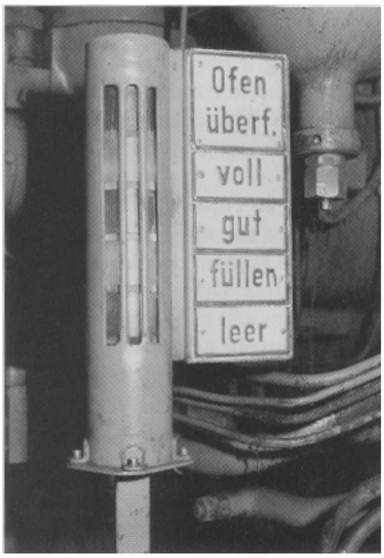

Fig. 6: Furnace level indicator with illuminated strip and labels from top to bottom indicating: Furnace Overflow, Full, O.K., Fill, Empty

distance, by the person responsible for filling the furnace. The setting of the switching points for the limit switches is made with the aid of the potentiometer on the limit switches and the position of the switching points can be read on the DA 24 by setting the channel selector switch appropriately.

As already explained, the shot time is modified in dependence of the weight of the furnace content to obtain fault-free castings. This change is made using control equipment. A base time for the shot is set in the controller and this time is then automatically optimized in relation to the weighed oven contents by adding a correction time. In addition the controller receives "good/bad" information from the limit switches monitoring the butt length. A further time correction is made by the controller on receiving a "bad" signal. The control equipment is adjusted on site before starting production. The base time per shot and the correction time required for a reduction of furnace content from 600 kg (1322 lb) to 300 kg (661 lb) were determined in calibration measurements.

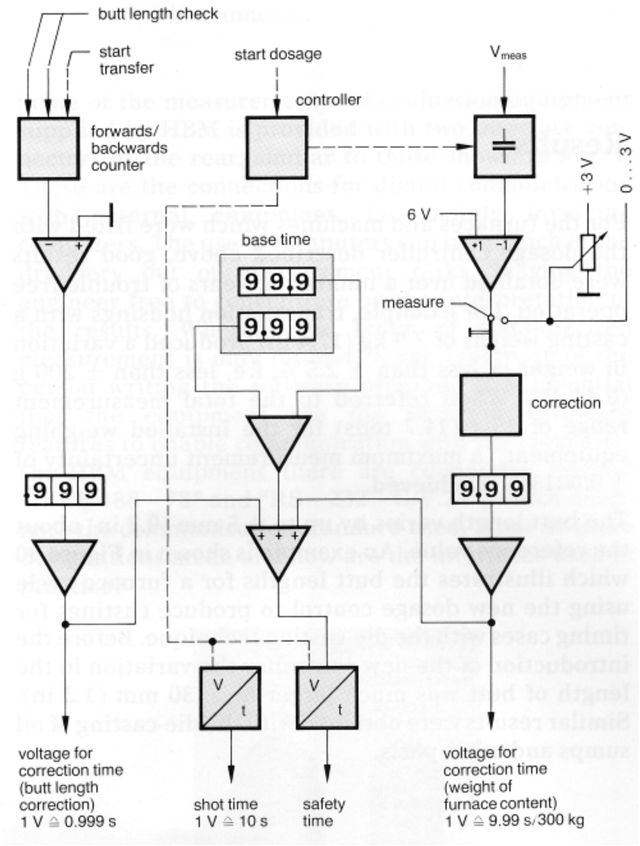

Fig. 7: Block diagram of the control equipment

To initiate a shot, the controller opens the compressed air valve and simultaneously closes the air vent. At the end of the shot the air vent is opened again and the compressed air valve closed. If the termination of the shot time is delayed by a fault in the controller, an additional changeover contact interrupts the metal dosing after a safety period which is set by a separate potentiometer. This prevents the emptying of the furnace due to a fault. The arrangement of the control equipment is shown in a block diagram in **Fig. 7** and the complete measurement and control system is shown in a block diagram in **Fig. 8**.

Figure 9 is a photograph of a 19" rack unit containing the measurement and control equipment. The units are from left to right the DA 24/S33 Digital Indicator as a special version, the MG 3150B 225 Hz CF Measuring Amplifier, the GR 225 Function Module with two limit switches, the control unit with the four three-digit button-type potentiometers for setting the time and the module with the potentiometer for setting the safety time period.

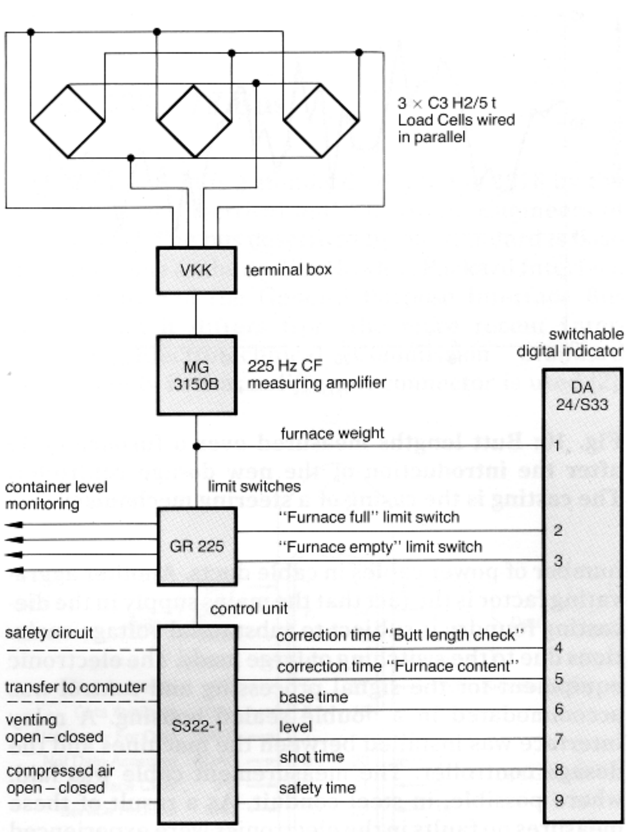

Fig. 8: Block diagram of the complete dosage equipment

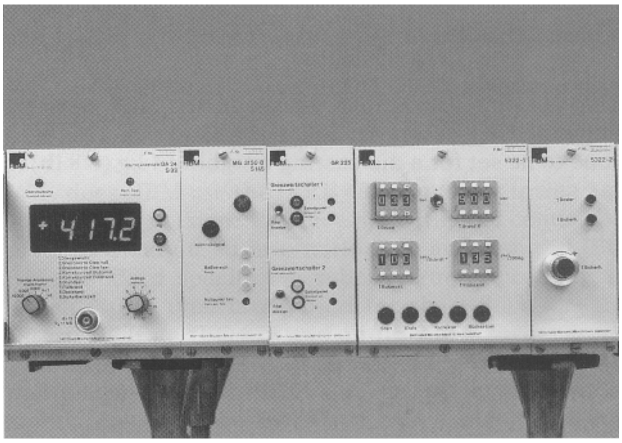

Fig. 9: Dosage equipment rack module

On account of the rough environmental conditions prevailing in a foundry and the numerous sources of electrical interference, a range of measures were undertaken to ensure the trouble-free operation of the dosage equipment. The main environmental problems were the high levels of temperature and humidity, together with high concentrations of gases and vapors. The load cell measurement cables which were about 15 m (50 ft) long and the machine control cables which were about 40 m (130 ft) had to be laid alongside a number of power cables in cable ducts. Another aggravating factor is the fact that the mains supply in the die-casting foundry is subject to substantial voltage variations due to the switching of large loads. The electronic equipment for the signal processing and control was accommodated in a double sealed housing. A relay interface was installed between the machines and the dosage controller. The measurement cable was laid, where possible, in steel conduit. As a result of these measures no faults in the electronics were experienced which could be attributed to extraneous influences.

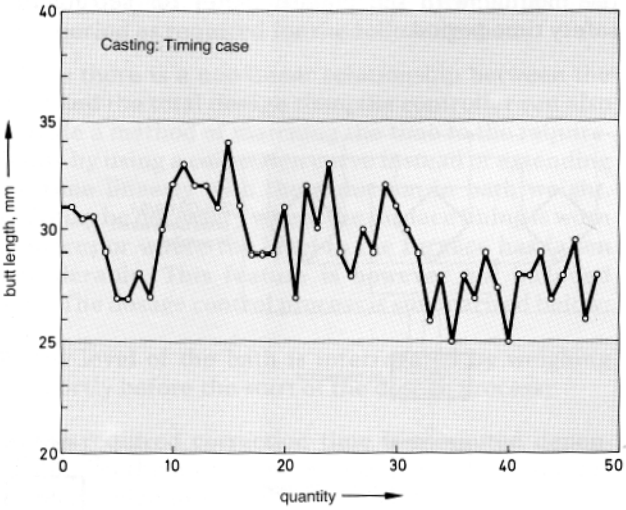

Fig. 10: Butt lengths measured over a furnace cycle after the introduction of the new dosage controller. The casting is the casing of a steering mechanism.

Dosage accuracy

The maximum possible dosage error will now be explained based on the following example. The base time to be set for a die-casting weighing 4 kg (8.8 lb) is about 5 seconds. It has been found from tests that a correction time of 0.75 seconds is needed to compensate the drop in level from "Furnace full" to "Furnace empty", i.e. a consumption of 300 kg (661 lb) of metal. If a weighing error of 0.03% now occurs, then this causes an error in the correction time of 0.0003 x 0.75 = 0.000225 s. When referred to the total dosage time of 5 s required for the quantity of metal for the casting, this produces a theoretical dosage error of 0.000045 x 4 = 0.00018 kg (0.00040 lb). It is obvious that errors of this magnitude are not relevant and should be regarded as purely theoretical. Other effects, e. g. clogging of the feed-pipe, have a substantially greater influence on the dosage error.

Results

For the furnaces and machines which were fitted with the dosage controller described above, good results were obtained over a number of years of trouble-free operation. For example, transmission housings with a casting weight of 7.9 kg (17.4 lb) produced a variation in weight of less than ± 2.5 %, i.e. less than ± 200 g (0.44 lb). When referred to the total measurement range of 15 t (14.7 tons) for the installed weighing equipment, a maximum measurement uncertainty of ± 0.0013 % is achieved.

The butt length varies by up to ± 5 mm (0.2 in) about the reference value. An example is shown in Figure 10 which illustrates the butt lengths for a furnace cycle using the new dosage control to produce castings for timing cases with the die-casting technique. Before the introduction of the new controller the variation in the length of butt was much larger at ± 30 mm (1.2 in). Similar results were obtained with the die-casting of oil sumps and other parts.

Dr.-Ing. Hans-Peter Braunger is a section manager in the Foreign Projects sector of Mercedes-Benz Untertürkheim, FRG. **Dipl.-Ing. Rudolf Hann** is a section manager working in process development with the same company.