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TRANSMISSION OF DATA-VALUES FROM A MAGNETICALLY SUSPENDED SAMPLE

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ABSTRACT

A surview on systems of free magnetic suspension for weighing in vacuum and controlled atmospheres is given. These devices are based on controlled axial attraction, axial repulsion with radial stabilization and radial repulsion with axial stabilization. If these systems contain inductive sensors for the position of suspended magnets, energy can be supplied to a measuring circuit inside the reaction chamber over the sensor. The signal for the measured variable can be transmitted back with the aid of analog to frequency conversion and demodulation outside the recipient, using the sensor as signal path.

SURVIEW OF SUSPENSION SYSTEMS DEVELOPED AS A COUPLING BETWEEN BALANCE PAN AND BALANCE

Magnetic suspension can be used for the complete separation of balance and object in cases where the first would be corroded or contaminated by the atmosphere in which the second is to be weighed.

Modes of magnetic suspensions as device for weighing

As fig. 1 shows, magnetic suspension can be obtained by attraction, axial repulsion and radial repulsion. At least one degree of freedom has to be restricted by a restoring force or by a control loop. In the first and third case it is the vertical degree of freedom, while in the second case two horizontal ones have to be restricted.

Suspension by controlled attraction

The system shown in fig. 2 consists of two bar magnets, the upper one provided with a control winding and a sensor coil, the lower one supporting a conducting plate or a coil as movable part of a distance meter. Both magnets are also enclosed in iron cups in order to reduce the stray field and increase the carrying force, which amounts to 30 g. According to fig. 3, the sensor coil is part of an oscillator and its inductance, which is influenced by the position of the lower magnet, determines the frequency. A discriminator converts the deviation of the frequency from a set point into a voltage signal.

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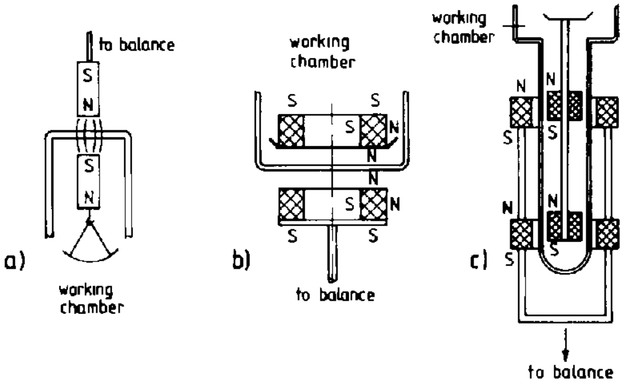
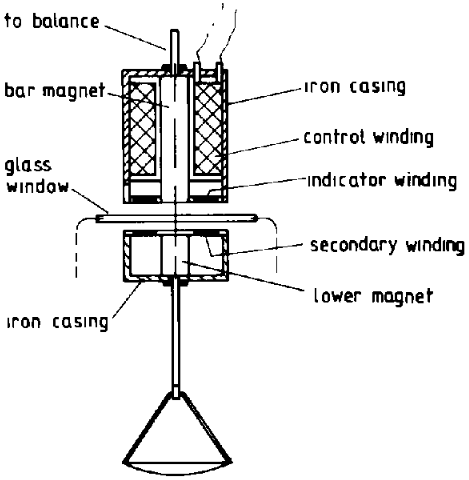


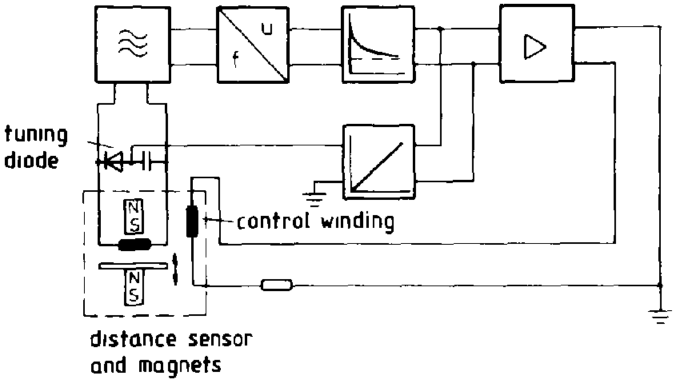
Modes of magnetic suspension as device for weighing

Figure 1



Suspension system with two-coil distance sensor

Figure 2



Control Loop of the Magnetic Suspension

Figure 3

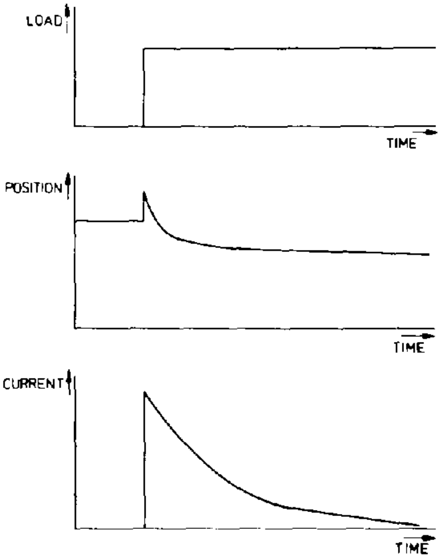


Figure 4

Load, position and current in a magnetic suspension as function of time

This signal is fed to a PID-controller whose output current flows through the control winding of the upper magnet. An auxiliary control loop which contains a varactor diode, varies the altitude setpoint in such a way, that the magnets carry the load without support or counter action by the controlling current. This is essential for sensitive weighing, because the heat developed in the control winding would otherwise generate convection and therewith cause spurious forces. A step in weight may illustrate the action.
Fig. 4 presents the course of position and control current as a function of time. Fig. 5 shows a model of the coupling.

Suspension by attraction for loads up to 3 g

The magnetic coupling shown in fig. 6 works with a photoelectric sensor. The control winding surrounds the two bar magnets and is fixed to the casing. A current flowing through the coil influences the mutual attraction of the nagnets. Spurious forces onto the pair of magnets would cause weighing errors. They are minimized by symmetrical arrangement of magnets with regard to the coil and - moreover - by the already mentioned auxiliary loop which reduces the mean control current to zero. Fig.7 shows the force which is generated by the coil and acts on the balance as a function of supported weight with deviation from symmetry as parameter . The system has to be shielded against external magnetic fields.

Suspension by axial repulsion and control in two coordinates

Two axially magnetized rings are used. The lower rests on the balance pan of a top pan balance while the upper one is kept in suspension by repulsion nd control in two horizontal coordinates, as it can be seen in fig. 8. A set f flat coils in the gap between the magnets produces the necessary horizontal orces. The position indicator uses a diffusely reflecting circular spot on he lower surface of the balance pan. The spot is brightly illuminated and rojected onto a plane, in which four photodiodes are arranged. If the upper agnet is moved from the central position, the pairs of photodiodes produce rror signals. These are converted into control currents which are fed to he coils.
ig.9 is the photograph of a model of such a suspension.

uspension by radial repulsion and axial stabilization

This mode of suspension is applied in the device according to fig. 10. t consists of two axially magnetized rings of cobalt samarium which are ttached to a frame and of two axially magnetized cylinders of the same aterial fixed to a vertical shaft which carries the balance pan. The cylinders

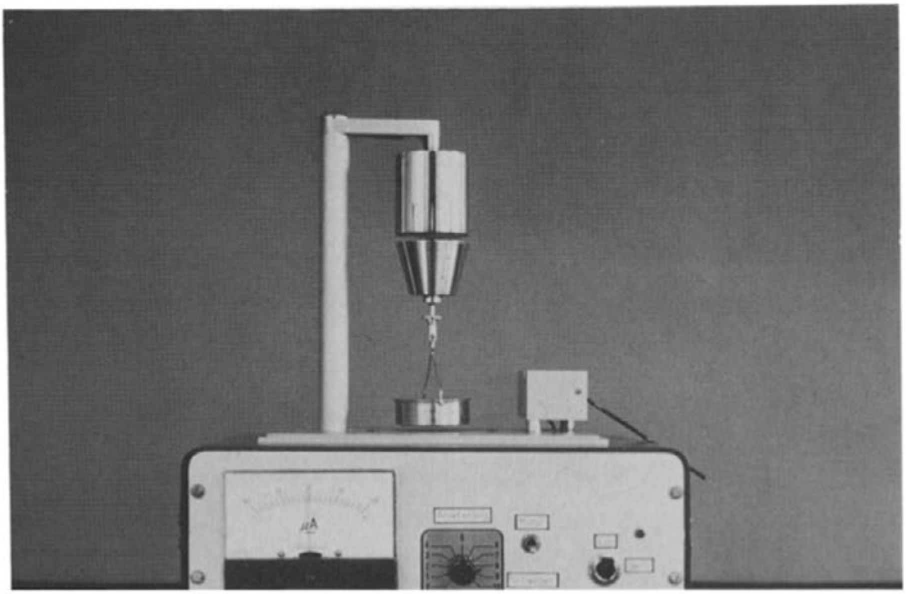


Figure 5 Model of the magnetic coupling

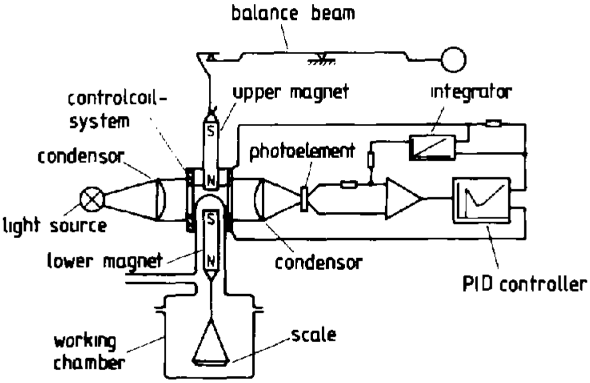


Figure 6 Suspension balance with bar magnets

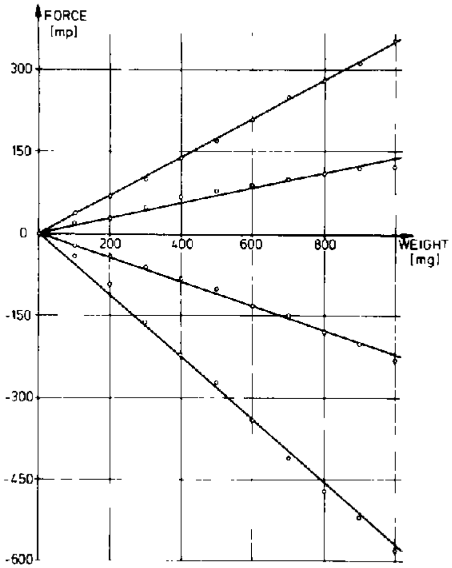


Figure 7

Force relationship with symmetry as parameter for a pair of rod shaped magnets in a cylindrical coil

reflector magnet

controlling coil

magnet

sensor

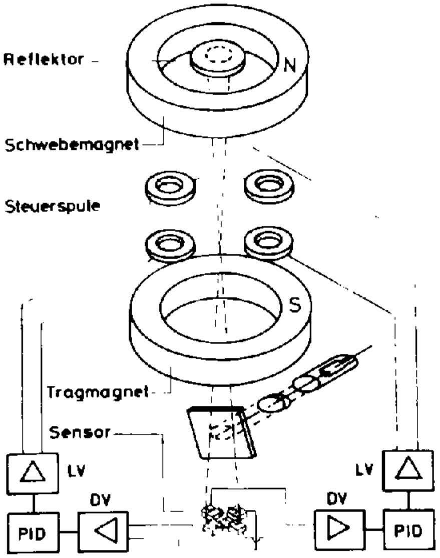


Figure 8 Magnetic suspension by repulsion and position control - coordinates

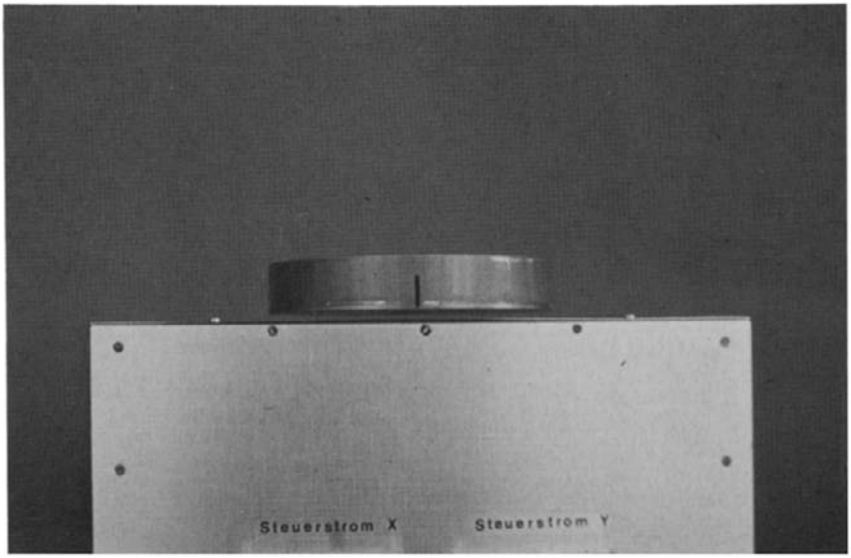


Figure 9 Model of a magnetic suspension

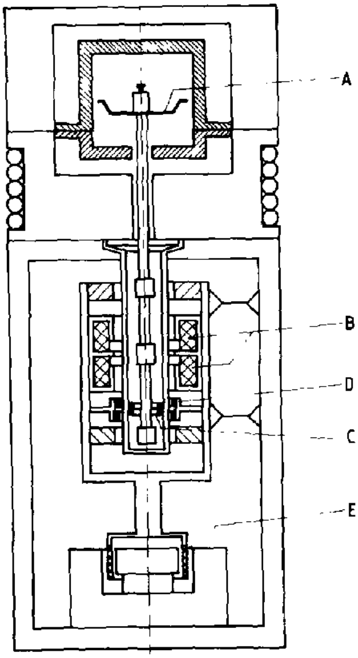


Figure 10 Balance for very high pressures

A	balance pan
B	controlling coils
C	metal ring
D	snesor coils
E	force coil

are centered within the rings by repulsion. A third one is attached to the shaft between the first and second, which acts together with an iron clad differential coil fastened to the frame as an actuator. A differential inductive sensor, consisting of two coils fixed at the frame and a nonmagnetic metal ring attached to the shaft acts as position detector. Actuator, detector and a PID-controller form the control loop for the axial position of the suspended system. Weights up to 20 g can be supported. The moving coil of an electromagnetic weighing cell is cemented to the frame, the latter being vertically movable and connected by flexural pivots to a balance beam and a guide bar. A quartz tube, closed at the lower end, separates the reaction chamber from the balance.
A system for use in atmospheres up to 5 kbar is in construction /2/.

Simultaneous measurement of force and torque

Two horseshoe magnets form the measuring system in fig. 11, which can be f.i. used to measure molecular weights after Knudsens method. The upper magnet carries control windings around its legs. To the lower one, which carries the container for the sample, a slab of insulating material is attached, provided with square copper sheets at its ends. The sheets act together with four sensors mounted in the nonmagnetic and highly resistive cover of the reaction chamber. The sensor coils are connected in a Wheatstone bridge shown in fig. 12. While the total resistance of the bridge is a measure of the mean distance between the pole faces of the magnets, and is not much affected by rotation or tilting, the diagonal voltage is a measure of rotation and only weakly affected by inclination.
A closed loop, containing the Wheatstone bridge, a three mode controller and the control windings, maintains the stable equilibrium of the magnetic suspension. The current through the control winding is a measure for the load applied to the lower magnet and is accordingly indicated, see fig. 13/1/.
In this state, an equilibrium position of the lower magnet exists, where the poles of the magnets stand face to face. A torque applied to the lower magnet will cause an approximately proportional angular deflection, a corresponding signal at the diagonal of the Wheatstone bridge and a voltage at the output of the torsion measuring channel. Because the conversion constant depends on the force of attraction which corresponds to the total weight, the output of the load measurement is led to a multiplicator inserted in the torsion signal path.
If the lower magnet is kept at a set altitude and turned by a certain angle, the length of lines of force increases. The current for the altitude control is therefore higher than without torsion.

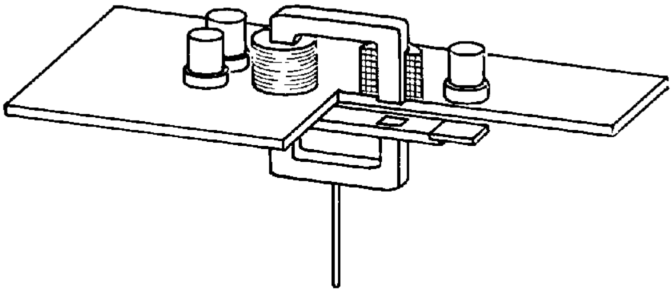


Fig. 11 Complete system for measurement of weight and torque

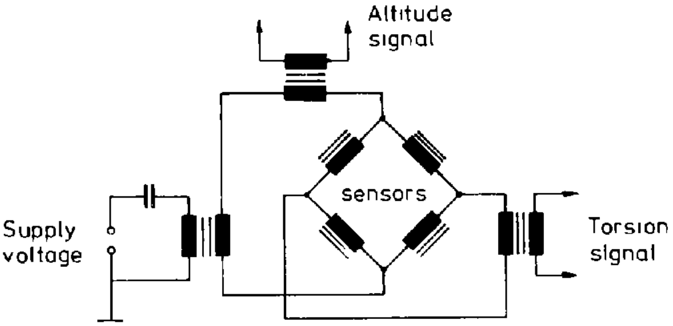


Fig. 12

Bridge connection of the sensors

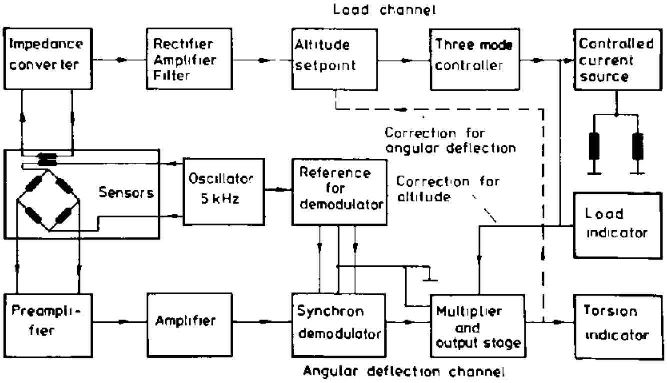


Fig. 13

Block diagram of the complete system

This can be corrected by feeding the torsion signal back to the altitude setpoint.

TRANSMISSION OF MEASURED VALUES FROM A FREELY SUSPENDED SAMPLE TO THE OUTSIDE OF THE REACTION CHAMBER

Kind of measured values and reasons for transmission over the magnetic gap

Temperatures of the sample in thermogravimetry, but also temperature differences for DTA and even DSC are of interest for thermal analysis. Other variables, as conductivity and permittivity could also be desired.

In the freely suspended state, transmission must of course be wireless. To maintain the suspension, a dielectric window between the upper and lower magnet is essential. Thus, a transmission across the magnetic gap presents itself as a device with low additional expenditure.

In order to convert the quantities to be measured into transmissible signals, energy has to be supplied to the measuring circuit. This can be done with the aid of the secondary winding around the lower magnet, see fig. 14. The winding is tuned and connected to a rectifier and filter and to a voltage regulator. In the case of thermogravimetry, the temperature is converted into a frequency with the aid of a Wheatstone bridge and a voltage controlled oscillator. The signal from the oscillator actuates a switch, which shortens the secondary winding for very small time intervals. This corresponds to amplitude modulation of the oscillator outside the reaction chamber. The signal of the oscillator is demodulated first with regard to amplitude and then with regard to frequency.

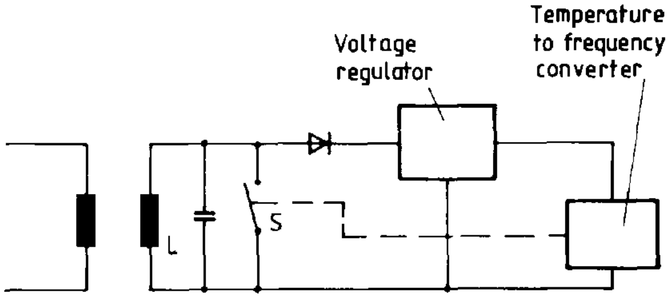
Because differential integrated amplifiers with very low energy consumption and very small offset drift are available, differential thermal analysis data can be transmitted in the same manner. This is shown in fig.15.

A pair of PT 100 thermometers is used to convert the difference of temperatures of sample and dummy into a voltage with the aid of a Wheatstone bridge.

In order to obtain a good linearity of the transmission, the same type of voltage controlled oscillator serves for the intial voltage to frequency conversion and for the final stage of reconversion into voltage. The scheme of a coupled TG, DTA-system is shown in fig.16 . It is to be seen, that the magnetic suspension system is enclosed in a thermostat which is provided with a dielectric cover and attached to the casing of the balance.

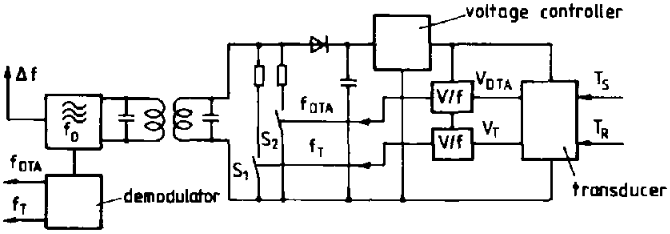
From the control circuit of the magnetic suspension, the demodulated signal of the oscillator is fed to a data processing unit.

Here, the frequencies for the temperature and temperature difference are converted into voltages and indicated. From the control circuit for the



Scheme of the telemetry arrangement in the suspension balance

Figure 14



Temperature transmission from the sample holder

Figure 15

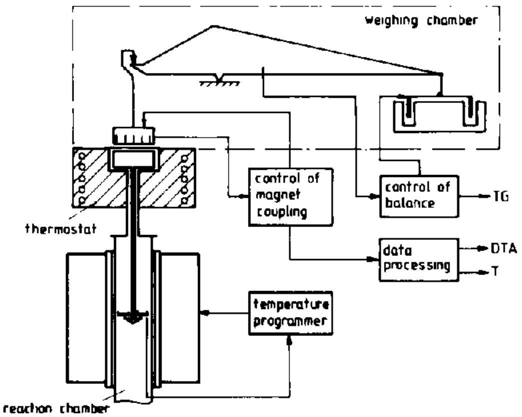


Figure 16
Thermoanalytical system

Schematic of the thermal analytical system

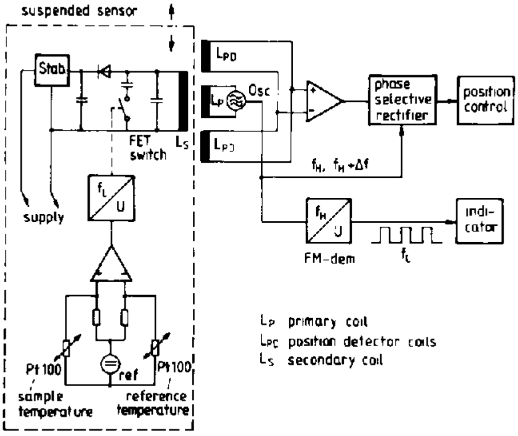


Figure 17

Transmission of DTA-Values from the Sample Holder balance beam, the compensating current is obtained, which can be converted into a digital indication of mass.

The other types of magnetic suspensions lend themselves to similar transmission of measured data from the sample.

As an example, the magnetic coupling for a high pressure balance is chosen, as it is shown in fig. 10.

The differential choke D is replaced by a differential system shown in the schematic diagram of fig. 17. This system consists of a primary coil L_P with two adjacent position detector coils L_{PD}, the three coils attached to the frame which is supported by the force coil E. Instead of the metal ring C, a secondary coil L_S is fixed to the shaft which carries the balance pan A.

The coil L_S is displaceable inside the coils L_P, L_{PD}, L_{PD}, varying the respective mutual inductances in a similar way as the metal ring has influenced the inductances in the differential choke. The coils L_{PD} are connected antiparallel, resulting in an alternating voltage signal proportional to vertical deflection. The signal is amplified and rectified sensitive to phase. A direct current signal results, which can be used for the position control of the magnetic suspension.

In the secondary coil a voltage is induced, which can be used for the power supply of the measuring circuit in the suspended subsystem of the balance.

By means of the platinum resistor Pt 100, the sample temperature and the reference temperature are converted into voltages. A differential amplifier forms the difference U of the signals, which is converted into a frequency f_L. Actuated by the output of the U/f_L-converter, a FET switch connects a small capacitance across L_S, thereby modulating the frequency of the oscillator. While the periodical change in frequency has no bearing on the position control, the frequency demodulated signal of the oscillator serves for the indication of the temperature difference. Using the same type of VCO in the signal path of the temperature difference as in the closed loop of the demodulator , a very good linearity is obtained.

A second channel can be provided which is reserved for the temperature of the sample. The voltage signal corresponding to this temperature generates a frequency, which determines the action of a second switch. Instead of a capacitor, a resistor is connected in parallel to the coil L_S, thereby modulating the amplitude of the carrier. The temperature signal is extracted from the oscillator by amplitude demodulation. In this manner, weight, sample temperature and DTA-signal can be transmitted from the freely suspended balance pan.

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