DENSITROL®

SPECIFIC GRAVITY
MEASUREMENT INSTRUMENTS

TECHNICAL DESCRIPTION

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DENSITROL® SPECIFIC GRAVITY INSTRUMENTS

The Princo Densitrol® line of specific gravity instruments has been in use for over 50 years. The sound engineering principles used in the original design have been retained through the various model changes and refinements. The continued growth and popularity of the instrument reflect the reliability of the basic design as well as the versatility exhibited by the many applications of the Densitrol®.

In order to understand the Densitrol® and its value to the process industry, some basic definitions and design functions are in order. The Densitrol® was designed to meet the requirements of industry for a system that continuously monitors the composition of flowing streams. Primary goals in the design were: Reliability; Sensitivity; Stability and Versatility. In simplest terms the Densitrol® develops a signal proportional to the existing liquid density and corrects this signal for unwanted temperature effects.

DEFINITIONS AND FORMULAS

Before examining the various design features of the Densitrol®, it is well to agree on terminology. Many of us use terms such as Specific Gravity, Density, API, etc., without too much attention to slight differences in meaning or reference bases.

Density is commonly defined as weight/volume. Units are usually pounds per cubic foot, or grams per cubic centimeter. As the volume of a material changes with temperature, the temperature at which the Density value is given is always stated, e.g.: D = 1.2 gm/cc @ 15 ºC.

Specific gravity is the ratio of the Density of a material to the Density of water. Since the units (gm/cc etc) of both densities are the same, the ratio is a pure number. It is necessary, however, to state the temperatures of both the material and the water, since both densities vary with temperature e.g.: S.G. = 1.1 at 100 ºF /60 ºF, indicating that the material (at 100 ºF) is 1.1 times as dense as water at 60 ºF.

For practical purposes, water is often considered to have a density of 1.0 gm/cc (at 4 ºC). When the density of a material is expressed in grams per cubic centimeter, the value is numerically equal to the Specific Gravity of the Material.

$$\mathbf{S.G.} = \frac{D_m}{D_w} = \frac{D_m}{1.0}$$

An important consideration in measuring liquid densities is the change of density with temperature. The Temperature Density Coefficient of a material varies with concentration and temperature. An average value is useful in applying temperature corrections to liquid density readings. For example, if the liquid density of a material is normally considered at 60 ºF, a correction must be applied when reading above or below 60 ºF. The true density of a material at 60 ºF would then be calculated by multiplying the TDC by the number of degrees of deviation, and then adding the correction to the reading at another temperature.

e.g. if $D_{68ºF}$ =1.020 and TDC = 0.0005/ ºF

then 0.0005 x (68 ºF – 60 ºF) = 0.004

and $D_{60ºF}$ = 1.020 + 0.004 = 1.024

The foregoing definitions are helpful in understanding the principle of the Densitrol® sensing system. If a material has a specific gravity greater than 1.0 it would sink when immersed in water but would rise to the surface if the specific gravity of the water increased to a higher value than that of the material. Such a change might take place by blending in a heavier liquid, or by cooling the water.

DENSITY SENSING

The sensing element of the Densitrol® is a chain-weighted plummet totally immersed in the process liquid. The chains are fastened in loops from the bottom of the plummet to a fixed reference point in the chamber through which the liquid flows. The portion of the chain from the bottom of the loop to the bottom of the plummet becomes part of the plummet weight. The plummet will either rise (picking up chain weight) or fall (losing weight) to attain an equilibrium position at which its weight/volume ratio equals that of the liquid. Further changes in liquid density will result in a change in vertical position of the plummet to reach a new weight/volume ratio. (See illustration, below)

Note that the plummet will respond to density changes whether caused by changes in concentration or changes in temperature. The position of the plummet is an indication of the existing density. To relate the density value to a composition value such as percent concentration or alcohol proof, the effects of temperature must be considered.

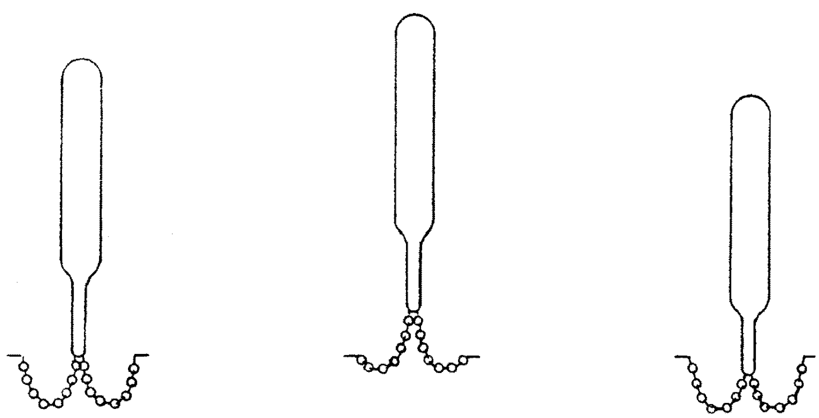
TEMPERATURE SENSING

In electrical models of the Densitrol® a resistance thermometer, in a simple bridge circuit, compensates for temperature effects. In direct indicating models, a simple re-positioning of the scale corrects the unwanted temperature effects.

INDICATION

In electrical models a Linear Variable Differential Transformer senses the position of the plummet. The plummet contains an iron core, the position of which is sensed by the LVDT mounted on the outside of the liquid chamber. Any given plummet position will produce a specific output signal from the LVDT, indicative of process density.

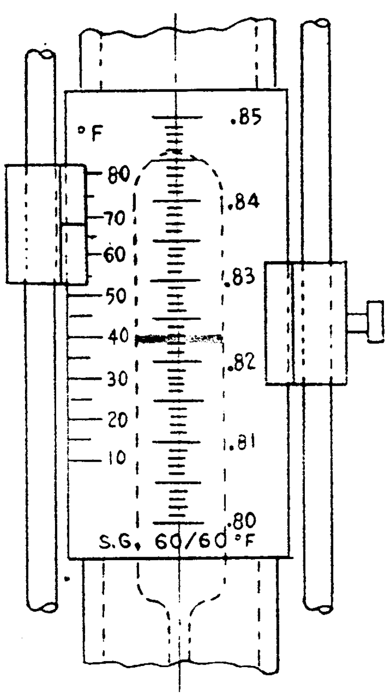
On the Direct Indicator Densitrol®, the position of the plummet is sighted, and read, through an external scale. The liquid must be reasonably transparent.



DIRECT INDICATING DENSITROL®

The Princo Direct Indicating Densitrol® instruments are rugged, simple, indicators of liquid density in a process stream. The sensor is a plummet, as described previously, installed in a Pyrex® chamber. The chamber is mounted between end flanges and carries an external scale. The scale is transparent and an indicator ring on the plummet is viewed through the external scale. A thermometer is included, and is mounted in the piping just ahead of the Densitrol® or in the chamber itself.

The range of the instrument is custom built to suit individual customer requirements. A temperature scale is also engraved at the side of the density scale, and is used to obtain temperature corrected readings without referring to charts or graphs. Any units (S.G., API, Proof, etc) may be selected for the scale, and the span to be covered may be as small as 0.02 Specific gravity or its equivalent in other units. The range may be as large as 0.5 S.G. or equivalent.



The value of the Temperature Density Coefficient is used to calculate the temperature scale so that spacing of temperature divisions is equal to the displacement of the plummet resulting from that temperature change.

To make a temperature corrected reading, the operator observes the temperature of the sample and re-positions the scale so that the existing temperature is opposite the temperature index. The temperature corrected value is then read directly on the density scale. Subsequent readings may not require resetting the scale. The operator checks the temperature and if no change has taken place, he reads the new density value immediately.

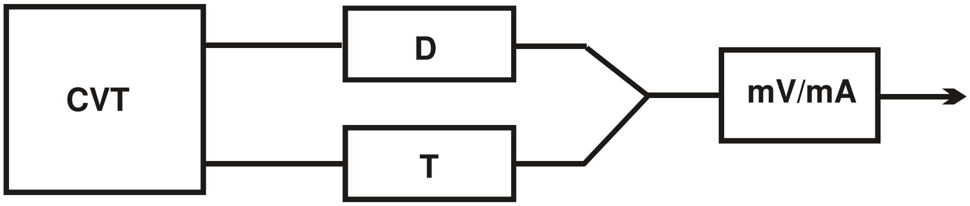
Advantages of the Direct Indicating Densitrol®, as compared to other simple indicators, often justify not only replacement, but additional indicators. The sample stream runs continuously through the chamber giving constant indication. The stream may be kept under pressure so that volatile fractions are not released and hazardous handling of the product is eliminated.

The operator is not required to correct readings before changing manual control settings and unusual conditions in the stream are immediately noticeable. Readings and control action can then be taken as required, rather than on a periodic, scheduled basis.

AUTOMATIC DENSITROL® MODELS

For remote indicating, recording and control of process streams, one of the various electrical models of the Princo Densitrol® will fit most applications. The solid-state circuitry used is extremely simple and reliable with practically no maintenance required. Circuit adjustments are made at start-up and further adjustments are seldom needed. Once the instrument has been "zeroed-in" under normal flow conditions, the output signal indicates the temperature corrected density automatically. During operation, the only moving parts are the chains and plummet in the process stream.

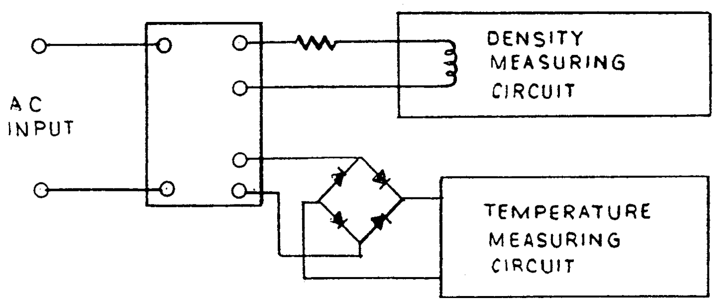
Functionally, this simplified diagram describes the automatic Densitrol® instruments:



The instrument consists of two sections, the sensor chamber, through which the liquid flows, and the remote integrator where signals from the sensors are measured and combined.

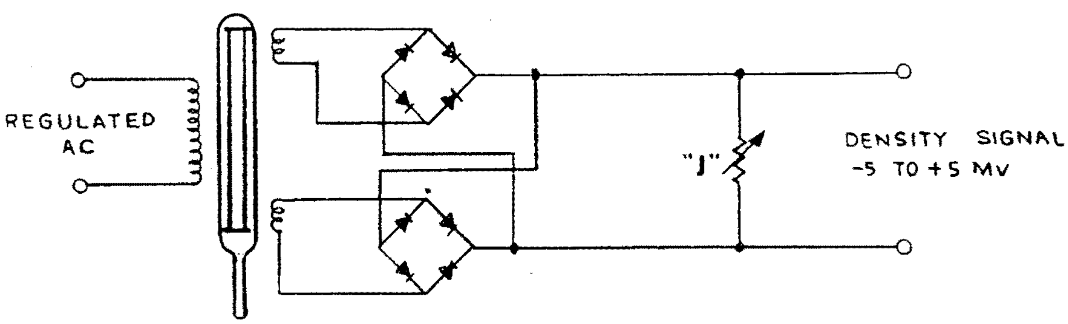
CONSTANT VOLTAGE CIRCUIT

The power supplied to the instrument is regulated by the constant voltage transformer, which accepts line voltage variations of 15% and reduces them to a 1% variation. There are two outputs from the CVT. One is applied to the primary coil of the LVDT, in the density measuring circuit. The other regulated output is rectified and fed to the temperature measuring circuit.



DENSITY MEASURING CIRCUIT

The linear variable differential transformer, mounted on the outside of the liquid chamber, consists of 3 windings, a center primary, an upper secondary and a lower secondary. An iron core, inside the plummet, provides a flux path from the primary to both secondary windings. When the plummet is displaced from its midpoint position, the flux linkage to one secondary is better than the flux linkage to the other, resulting in a larger signal from the secondary toward which the plummet moved. Bridge rectifiers rectify the voltage signals from each secondary winding and the two resultant signals are compared. The upper secondary creates a positive output and the lower secondary a negative output. The two signals are added by impressing them across a range resistor so that their algebraic sum appears as the output signal. The range resistor is adjusted to a signal of –5 to +5 milli-volts as the plummet responds to its calibrated density range. Each plummet is custom built and a span, as small as .005 S.G., may be selected.



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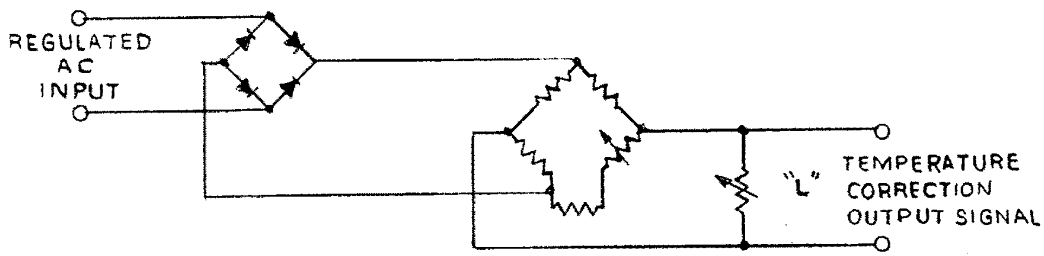
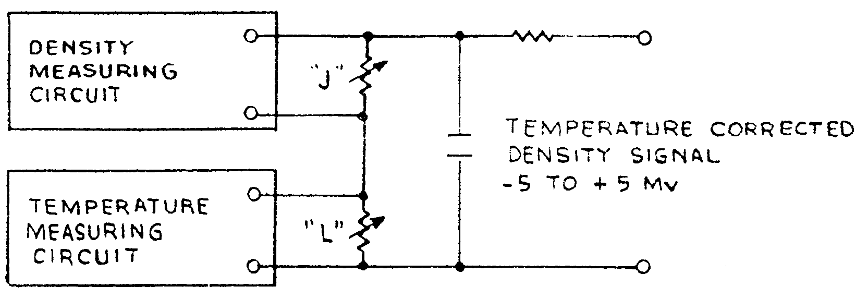
TEMPERATURE MEASURING CIRCUIT

A resistance thermometer, mounted in a well in the liquid chamber senses sample temperature. A Wheatstone bridge circuit, including the resistance thermometer, then provides an output milli-voltage signal, which adds to the density signal. A variable resistor, in series with the resistance thermometer, is used to set the balance of the bridge at average operating temperature. As temperature deviates from the set condition, the bridge becomes unbalanced and develops a voltage across the temperature correction span resistor. This resistor is adjusted to produce an equal, and opposite, signal to that produced by re-positioning of the plummet because of temperature change.



The density and temperature correction signals are then combined to give a temperature corrected density indication, and the signal is filtered.



The –5 to +5 mV signal is converted to a milliamp (e.g. 4-20) output to drive indicators controllers etc.

APPLICATION INFORMATION

Complete specification details for the various models can be found in the latest catalogs. Some discussion of the performance characteristics will help in selecting the features needed for a particular application.

RANGE

Practical size limitations and availability of chain variations are the primary factors in setting range limits. The chain, whose weight is incrementally, added to the plummet, determines the span of the instrument. Plummet travel can be reduced and lighter chains used to respond to small density variations. Plummet volume and weight are also increased so that the incremental chain weight is less significant.

DENSITY

The same physical factors that affect range also determine practical density values. Plummets can be built for densities as low as 0.5 S.G., but if heavy chains are required (for wide range) the material of the plummet may have to be reduced to the point of seriously weakening the walls of the plummet.

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PRESSURE

The plummet is one factor in high-pressure applications. Plummets of Pyrex® can be built to withstand 500 psi even when low-density values require light construction. If wide range is also a requirement, the heavy chains will take up an appreciable part of the allowable weight of the plummet and reduce the possibility of high-pressure rating.

Metal plummets are limited to 60 psi. For units utilizing Pyrex® or Teflon®-lined sensor chambers the pressure limitations are 50-100 psi depending on conditions.

VISCOSITY – FLOW EFFECTS

Since there is a constant flow through the chamber, the plummet is subject to viscosity-flow effects.

Viscosities lower than 50 Centipoise are usually not troublesome.

Normally, the flow rate is kept to approximately 0.5 gallons per minute. Higher rates will tend to push the plummet upward until the additional chain weight equalizes the force of flow on the plummet. Lower rates to minimize viscous flow effects can be used but care should be taken not to introduce excess lag in the process.

TEMPERATURE

Typically the Densitrol® has been used to temperatures below 0 ºF and up to 230 ºF without difficulty. Temperatures to 450 ºF can be used by selecting high temperature components. The variation of temperatures in a given process must also be considered. Each increment of temperature change moves the plummet and produces an equal and opposite signal from the compensation circuit. If the plummet moves too far it will leave the linear portion of the pick-up coil and introduce error. In addition, the correction circuit produces a signal based on an average TDC value.

In some liquids the TDC varies enough over a relatively narrow span of temperature and concentration to introduce errors beyond the overall 3% accuracy of the Densitrol®. Small ranges of concentrated alcohol, for example, may exhibit temperature related errors of as much as 2% when temperature varies 30 ºF.

MAINTENANCE AND TROUBLE-SHOOTING

The Densitrol® is inherently trouble free and does not require periodic calibration, lubrication, or adjustment. If the process liquid does have a tendency to coat the plummet or to deposit solids in the chamber, a periodic schedule of cleaning and examination of the plummet and chains may be established.

No parts require lubrication and calibration is performed only at start-up.

If a signal converter is included, calibration may be checked periodically if ambient temperature changes significantly (50F = 1% drift).

When incorrect or erratic results are observed from a Densitrol® and its associated system components, it is advisable to attempt to isolate the troublesome section before starting individual component checks. A typical system is shown as follows:

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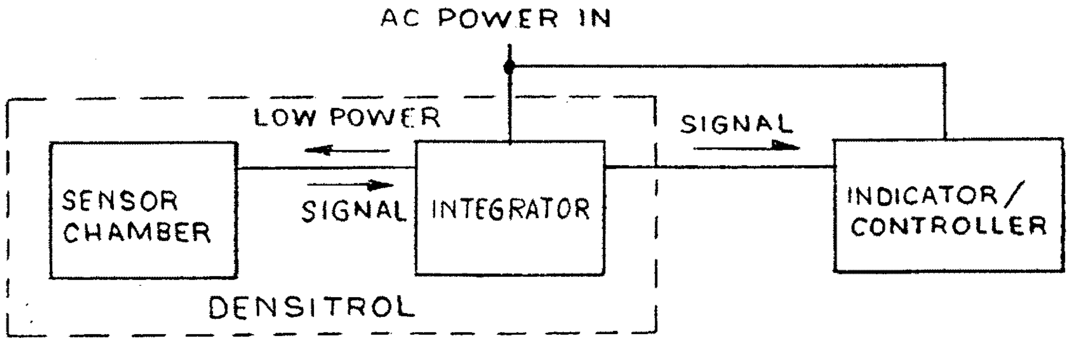

POWER SUPPLY

Start by checking power input to the integrator and indicator. The sensor chamber gets power (less than 6 volts AC) from the integrator.

INDICATOR

Substitute a millivolt (or milliamp, as appropriate) source for the Densitrol® to eliminate the possibility of a faulty indicator. Always substitute at the Densitrol® end of connections to include interconnecting wiring in the test.

DENSITROL®

If the indicator is operating normally, reconnect and proceed with the Densitrol® trouble-shooting. Various conditions may suggest particular areas to be checked and the instruction manual covers these in detail. In general, however, the block diagram preceding can be further broken down to isolate sections of the major components.

SENSOR CHAMBER

There are three sections to be examined in the sensor chamber; the plummet assembly, the LVDT, and the resistance thermometer.

1. Plummet Assembly – Examine for broken or clogged chains. Look for built-up coatings on the plummet and chains which would change calibration. Look for leaks, no liquid should be present in the plummet.

2. LVDT – Examine the coil for evidence of physical damage or deterioration caused by corrosive liquids or atmospheres. Examine the connections and tighten wiring joints at terminal strips and plug-in connections. Check electrically by referring to the manual.

3. Resistance Thermometer Assembly – Check for the same conditions as under #2 above.

4. Make sure that proper flowing conditions exist during normal operation.

INTEGRATOR

A visual and mechanical inspection of the chassis and connecting wiring should be performed first. For further checks the Integrator can be divided into sections as follows:

1. **Constant Voltage**: Examine the transformer and its associated capacitor for mechanical difficulties such as broken leads or oil leakage from the capacitor. Check electrically as described in the manual.

2. **Density Circuit**: This can be isolated from the automatic temperature compensation circuit (if present) by turning the Temperature Density Coefficient setting (resistor "L") to zero. This short-circuits any output from the A.T.C. circuit. Drain the sensor chamber and mechanically position the plummet in the chamber to be approximately centered in the coil. If the indicator does not indicate mid-scale check the components of the density circuit. If the indicator does respond normally, move the plummet up and down. A few centimeters travel should produce full-scale indication. If not, check density components.

3. **A.T.C. Circuit**: To eliminate the density circuit, place a short circuit across resistor "J" on the resistor board. (In some cases J is a single fixed resistor, in others it is a combination of fixed and variable resistors. Be sure to short circuit the entire "J" value). Restore the TDC setting and substitute a decade box for the resistance thermometer at the sensor chamber. Set the box for about 50 ohms and trim to get a mid-scale reading. Further increments of 1 ohm should produce approximately the same indicator response as a 10F change would produce without ATC. For example, in a Densitrol® having a TDC/ F of .35% of range, a 10F change would move the plummet 3.5% of range. Since the plummet output (J shorted) is fixed, only the ATC circuit result will be visible.

   If the procedure above gives incorrect readings, check components. If erratic results, or drift, are evident, look for loose wiring connections or variable contact resistance in resistors L, N, or M.

4. **Signal Converter**: Check power input. Disconnect the –5 to +5 mV input signal leads and substitute a millivolt source. This procedure eliminates all other Densitrol® circuitry and faulty response at the indicator would localize trouble in the converter or the connections to the indicator. Follow the information in the manual for checking the converter.