

Direct Drive Bourdon Basics
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Named for its inventor, Eugene Bourdon, the Bourdon tube is a curved, flattened piece of tubing, closed at one end, which tends to straighten when a pressure is applied to its open end. It is used in pressure measuring devices with a gear/lever mechanism to magnify its small movement to a larger rotation of a shaft to which a pointer is attached. In its early form, the curved tubing covered about 270° and the movement at full scale pressure was about 0.1 inch. The gear/lever mechanism was used to give a pointer arc of about 270° with a dial graduation in pressure increments. This is popularly known as a “C-tube”. In later forms, the tube sometimes has several revolutions to increase the movement and is referred to as a “helix-tube”.

In the mid-1900's, Dino Morelli patented a mechanism using small diameter (0.030-0.100 inch outside diameter) tubing with multiple turns to give a direct rotation of 70° degrees or more. Thus, the direct drive helical Bourdon coil, which eliminated the requirement for the gear/lever mechanism. The gauges nominally have one moving part, are inherently frictionless, have no dead band and indicate pressure directly with a pointer attached to the free end of the Bourdon coil.

The development of any Bourdon tube or coil is primarily empirical. Many mathematical analyses have been done to determine the movement and stresses of a specific configuration. However, the variability of the flattened cross-section in actual manufacturing has limited the usage of any formulas developed. The cross-sections that are produced can vary from an ellipse through a flat sided “race track oval” to a “dog bone” shape. Any of these can be successful as a mechanism for the creation of a pressure gauge.

In development, the usual “givens” are the pressure range, the dial arc desired and the limiting envelope dimensions. The material for small helical Bourdon coils is usually limited to heat-treatable Inconel, Ni-Span C or beryllium copper. Beryllium copper has a smaller Young's modulus and the movement at a given stress will be greater. All of these materials are available in small diameters and can be formed in the annealed condition and then precipitation hardened with heat to a high yield strength. There are many variables to be considered in the development of a Bourdon coil: the material, the outside diameter and wall thickness of the tubing all of which are sometimes limited by inventory availability. Therefore, the usual development of a Bourdon coil consists of an educated choice of the tubing diameter and wall thickness and an experimental choice of flatness, mandrel diameter and number of coils.

Proof pressure is an important parameter. Proof pressure is defined as the highest pressure that the gauge will see in normal (or somewhat abnormal) conditions in the system in which it is used. The calibration of a gauge shall not change after exposure to the proof pressure. The system proof pressure is normally specified by the customer and is ideally based upon a realistic analysis of the actual maximum operational system pressure. The inherent proof pressure of a Bourdon coil is determined by the coil design. Pressure above the inherent proof pressure will cause a zero shift of the Bourdon coil. The inherent proof pressure is determined by applying a pressure, returning to zero pressure and seeing if there was a zero shift. If not, a higher pressure is tried. The inherent proof pressure is an important parameter because it determines the maximum system proof pressure for a given coil.

The sensitivity of a Bourdon coil is defined as the movement of the tip of the coil at a given pressure input. For the old “C-shaped” tube it is given as “inches at full scale pressure.” In helical Bourdon coils it is called “arc” and is given as “degrees at full scale pressure.” The sensitivity (arc per pressure unit) is affected by the tubing diameter, the tubing wall thickness, the flatness of the cross-section, the helical diameter and the number of helix turns. The stress in the coil material is affected by the first four but is not affected by the number of turns. The goal is to get as much arc as

possible while meeting the system proof pressure. The physical size of the desired gauge dictates the maximum helical diameter and the number of turns due to the gauge diameter and length; plus there is a manufacturing minimum for the wall thickness and a practical minimum for flatness.

For example, the arc at the inherent proof pressure (for a typical coil configuration) may be as much as 540 degrees. If the desired system proof pressure is only 150% of the full scale pressure, you can have a full scale arc (and, therefore, dial) of 360 degrees. If, however, the proof pressure is 10 times the full scale pressure, the dial arc can only be 54 degrees. A system designer must take this into account when specifying dial arc at a given pressure and the desired system proof pressure.

To increase the sensitivity (dial arc per pressure unit) of the gauge, the system designer must increase the size of the gauge or reduce the specified system proof pressure.

Note 1: Bourdon tubes can also be made in a spiral pattern or with coaxial multi-layers. This treatise is also applicable to those designs. Even a twisted Bourdon tube has been used.

Note 2: There is no practical way to “compress” or “extend” the movement of a helical Bourdon coil as is sometimes done with c-tubes. The movement is nominally linear. Stops can be installed to limit the pointer movement, but the movement is linear between the stops and would be nominally linear from the minimum stop down to zero pressure.