Strain-Gauge Measurement of Weight of Fluid in a Tank

This method is nonintrusive and independent of the nature of the fluid.

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A method of determining the amount of fluid in a tank is based on measurement of strains induced in tank supports by the weight of the fluid. Unlike most prior methods, this method is nonintrusive: there is no need to insert instrumentation in the tank and, hence, no need to run wires, cables, or tubes through the tank wall. Also unlike most prior methods, this method is applicable even if the fluid in the tank is at supercritical pressure and temperature, because it does not depend on the presence of a liquid/gas interface (as in liquid-level-measuring methods).

The strain gauges used in this method may be of two types: foil and fiber-optic. Four foil gauges (full bridge) are mounted on each of the tank-supporting legs. As the tank is filled or emptied, the deformation in each leg increases or decreases, respectively. Measured deformations of all legs are added to obtain a composite deformation indicative of the change in weight of the tank plus fluid. An initial calibration is performed by recording data at two points (usually, empty and full) for which the mass or weight of fluid is known. It is assumed that the deformations are elastic, so that the line passing through the two points can be used as a calibration curve of mass (or weight) of fluid versus deformation.

One or more fiber-optic gauges may be used instead of the foil gauges. The resolution of the fiber-optic and foil gauges is approximately the same, but the fiber-optic gauges are immune to EMI (electromagnetic interference), are linear with respect to temperature over their entire dynamic range (as defined by the behavior of the sample), and measure thermally induced deformations as predictable signals. Conversely, long term testing has demonstrated that the foil gauges exhibit an erratic behavior whenever subjected to direct sun radiation (even if protected with a rubberized cover). Henceforth, for deployment in outdoor conditions, fiber-optic gauges are the only option if one is to rely on the system for an extended period of time when a recalibration procedure may not be acceptable.

A set of foil gauges had been tested on the supports of a 500-gallon (1,900-liter) tank. The gauges were found to be capable of measuring the deformations (up to 22 micro-strain) that occurred during filling and emptying of the tank. The fluid masses calculated from the gauge readings were found to be accurate within 4.5 percent. However, the reliability of the foil gauges over a few hours was not acceptable. Therefore, the foil sensor system is acceptable for use only in controlled environments (complete shade, or indoors).

The fiber-optic sensors are reliable and at least as accurate as the foil sensors (possibly more). The fiber-optic system consists of one or more sensors mounted on the structure, a temperature sensor also mounted on the structure, and a reference fiber-optic sensor mounted on a plate made of the same material as the tank-supporting legs, that is not subjected to any mechanical load. An important element to consider is the thermal deformation of the structure, which is not going to be exactly the same as that of the reference plate. This is because the structure has appendages (pipes, etc.) that must be taken into account for temperature compensation. The procedure to calculate a compensated measurement (a measurement reflecting the mass contents of the tank) using the fiber-optic system is as follows: First, one must characterize the structure as it deforms due solely to thermal effects by taking measurements over its operating temperature range, when the tank is empty. During this characterization procedure, deformation and temperature measurements are taken from the sensors attached to the structure (strain and temperature) and the sensor attached to the reference plate (strain). With this information, a tabulated or graphical tool is developed such that at any given temperature, the reference signal is subtracted from the structural signal, and further modified by a value that depends on the structure's temperature. Note that the characterization of the structure as it deforms due to temperature variations may also be done by analytical methods that can model the process. In that case, the experimental characterization is not needed.

It may be possible to increase accuracy further by increasing the signal-to-noise ratio through the use of more deformable tank-supporting legs, larger gauges that measure larger deformations, or other methods to increase the strain in some part of the tank support structure.

This work was done by Jorge Figueroa, William St. Cyr, and Shamim Rahman of **Stennis Space Center** *and Gregory McVay, David Van Dyke, William Mitchell, and Lester Langford of Lockheed Martin Corp.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Intellectual Property Manager, Stennis Space Center, (228) 688-1929. Refer to SSC-00187.

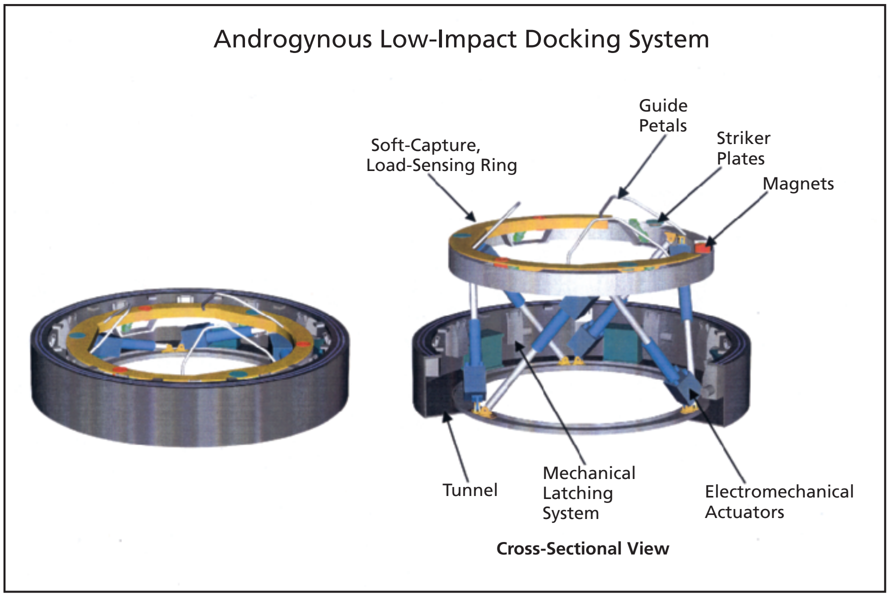
Advanced Docking System With Magnetic Initial Capture

Speeds of approach, and thus docking forces, could be relatively small.

Lyndon B. Johnson Space Center, Houston, Texas

An advanced docking system is undergoing development to enable softer, safer docking than was possible when using prior docking systems. This system is intended for original use in docking of visiting spacecraft and berthing the Crew Return Vehicle at the International Space Station (ISS). The system could also be adapted to a variety of other uses in outer space and on Earth, including mating submersible vehicles, assembling structures, and robotic berthing/handling of payloads and cargo.

Heretofore, two large spacecraft have been docked by causing the spacecraft to approach each other at a speed sufficient to activate capture latches — a procedure that results in large docking



This Graphical Representation Depicts a Demonstration Version of the advanced docking system for use in berthing an X-38 spacecraft at the International Space Station.

loads and is made more difficult because of the speed. The basic design and mode of operation of the present advanced docking system would eliminate the need to rely on speed of approach to activate capture latches, thereby making it possible to reduce approach speed and thus docking loads substantially.

The system would comprise an active subsystem on one spacecraft and a passive subsystem on another spacecraft with which the active subsystem will be docked. The passive subsystem would include an extensible ring containing magnetic striker plates and guide petals. The active subsystem would include mating guide petals and electromagnets containing limit switches and would be arranged to mate with the magnetic striker plates and guide petals of the passive assembly. The electromagnets would be carried on (but not rigidly attached to) a structural ring that would be instrumented with load sensors. The outputs of the sensors would be sent, along with position information, as feedback to an electronic control subsystem. The system would also include electromechanical actuators that would extend or retract the ring upon command by the control subsystem.

In preparation for docking, one spacecraft would move to a position near (but not touching) the other spacecraft, with the docking ports of the two spacecraft in approximate alignment. Then while one spacecraft maintained an approximately constant position relative to the other spacecraft, the actuators of the active subsystem would be made to extend the ring, gently pushing the guide petals and electromagnets toward the passive ring guide petals and magnetic striker plates: in effect, the active subsystem would reach out, comply, and grab the passive subsystem.

During this reaching out, the hardware and software of the feedback control subsystem would command the actuators to respond to sensed loads to correct for any misalignments between the docking ports, i.e., to comply. The reaching-out-and-alignment process would continue until the limit switches indicated soft capture — i.e., final petal alignment and magnetic capture of the magnetic striker plates. Once soft capture and alignment was complete, the ring would be retracted, then mechanical latches would be engaged to secure the docked spacecraft to each other.

The active subsystem ring, electromagnets, and petals would then be withdrawn, and the latches would continue to hold the spacecraft together. Later, the undocking could be effected by releasing the mechanical latches.

This work was done by James L. Lewis of **Johnson Space Center** *and Monty B. Carroll, Ray Morales, and Thang Le of Lockheed Martin.*

This invention has been patented by NASA (U.S. Patent No. 6,354,540). Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Johnson Space Center, (281) 483-0837. Refer to MSC-22931.