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TECHtalk

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Industrial Balances Applying Tuning Fork Technology

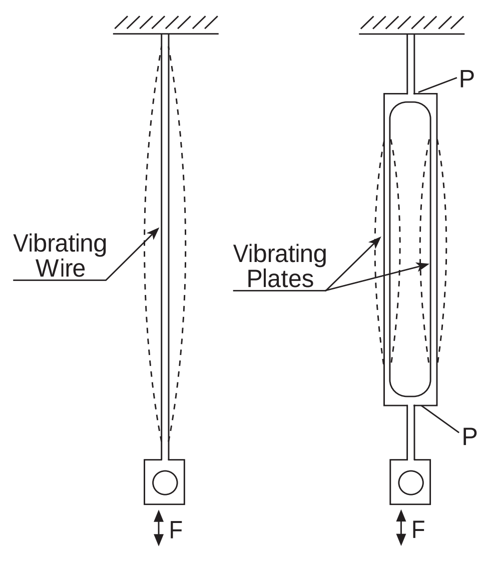
1. Summary of Vibrating Force Technology

Since the 1960's, many studies have been conducted on vibrating sensors and their practical applications for force measurement. In those studies, precision balances utilized a vibrating wire system as the force measuring element. However, due to many problems common in vibrating sensing methods, their accuracy and marketability seemed to be limited. Studies conducted over the past three decades utilizing the double-ended tuning fork (DETF), were found to have higher accuracy than any other force measurement system. Strangely, the DETF technology hasn't been put to practical use until recently. The reason for this is due to several technological obstacles such as stress and strain caused by assembly, sensor sensitivity, flexure flexibility, and leaking oscillating energy signals. Each of these obstacles have been addressed and overcome in Ishida's line of precision DETF balances. This TECHtalk discusses the construction of these unique balances and how Ishida overcame the obstacles in order to provide precision balances with unparalleled accuracy.

2. Construction of the Tuning Fork Vibrator

The assembly and fabrication of the DETF vibrator represented some major obstacles to effectively applying this technology to precision balances. For example, when one tries to measure a force with a vibrating sensor, the sensor must be sensitive to the applied force. For this reason, ribbons, beams, or wires are commonly used as vibrators. However, these various types of sensors are also sensitive to other disturbing forces such as ones perpendicular to the axis or twisting movements. Additionally, if a vibrator is assembled from several parts, stress and strain will be caused by the assembly which results in hysteresis and low repeatability. To avoid stress and strain, the Ishida DETF vibrator is cut entirely out of an alloy material in the shape of a common tuning fork with the tines joined at each end.

Figure 1 compares the construction of a standard vibrating wire system and the DETF vibrator. Both sensors establish the force (F) by measuring the resonant frequency. The vibrating element in a DETF vibrator consists of a pair of rectangular flat plates symmetrical to the center axis and parallel with each other; they oscillate at a fundamental frequency with the symmetrical mode shown by the broken line in Figure 1B. Two piezo-ceramic transducer elements are positioned close to the lower end of the vibrating plates. One piezo-ceramic element connects to the output terminal and the other to an amplifier input terminal. Together they constitute a stimulation and detection circuit to maintain vibration—one for exciting and the other for sensing.



1A. Wire *1B. Tuning Fork*

Figure 1. Vibrator

Another obstacle that had to be overcome was the stress and strain caused by the attachment of the DETF vibrator to the loading mechanism. To help minimize this stress and strain, strip flexures were added to the DETF vibrator as shown in Figure 2. These flexures support the vibrator by absorbing disturbing forces and reducing unwanted influences from such sources as machinery or a passing forklift.

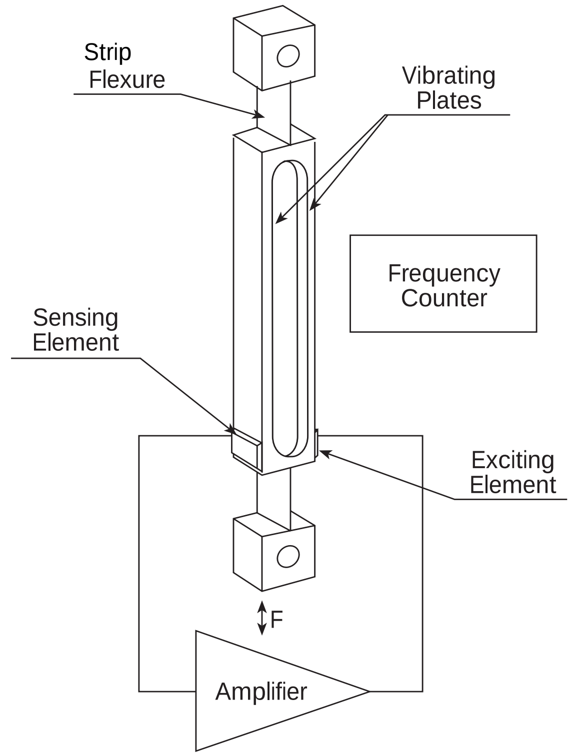


Figure 2. Tuning Fork Measuring System

3. Tuning Fork Sensing Unit

Although the addition of strip flexures reduced the stress and strain of the DETF vibrator, that change alone was not sufficient to produce the accuracy required in precision balances. This was due to the force sensor being too sensitive and the flexures not being flexible enough. To reduce such unfavorable effects and measure expected force exactly, Ishida developed the DETF sensor shown in Figure 3.

Also cut entirely from an enlivar material, the sensor consists of a DEFT vibrator with flexures, a lever, a fulcrum point, a loading element, and a base with fixing holes. When a force pulls down on the loading point, a tension is applied to the DETF vibrator via the lever and flexures.

The first advantage of this type of sensor is that stress and strain due to improper installation or other causes will not be generated. Secondly, asymmetrical vibrations will not occur, because even forces are applied to the vibrator's vibrating beams. Combined, these advantages nearly eliminate hysteresis and slow response.

Another advantage of the DETF sensor is its ability to protect the vibrator from being buckled or damaged if compression is applied that exceeds its critical load. This is accomplished by the addition of an escape mechanism to the DETF sensor. The vibrator in the unit remains safe because compression applied to it is limited within its critical load by the bending movement of the flexible loading element.

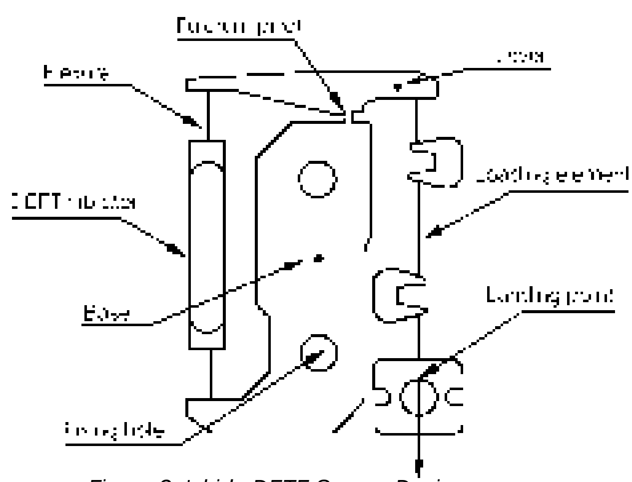


Figure 3. Ishida DETF Sensor Design

The development of the DETF sensor eliminated many of the obstacles blocking the practical use of the DETF vibrator. However, Ishida still had to overcome the problem of leaking oscillating energy signals when the supporting element resonated. This occurrence was caused by the mechanical connection between the vibrator and the sensor. The leak through this connection generated a frequency resonance between the parts of the sensor and the load transmitter/receptor.

Ishida's approach to finding a solution to the resonance problem was carried out by analyzing leaking energy signals in two directions: horizontal and vertical. The analysis of the horizontal direction found that the difference in the thickness of the two vibrating beams caused the leaking energy signals. To compensate for this, Ishida designed the flexures in geometric proportions to reduce leakage and give the vibrator pertinent frequency. For vertical direction, a similar study was conducted and Ishida also effectively minimized leakage in this direction.

4. How Does the Tuning Fork Sensor Provide Higher Accuracy?

To obtain high accuracy, a scale must compensate for the influence of temperature variation at the force sensor. The temperature error of a tuning fork balance is extremely small, possibly minimized within ± 1.5 ppm after compensation. This is due to several factors.

In the DETF sensor, the temperature increase caused by self-heating can be disregarded since the sensor has extremely low heat capacity and good conductivity. The DETF vibrator requires a very small amount of excitation energy, allowing it to have very simple temperature distribution and heat transfer characteristics. This is not the case with strain gauge load cells or an electromagnetic compensation system. Additionally, the DETF sensor doesn't require any A-D converters, analog circuits, or magnetic circuits which cause complex temperature characteristics. This allows the balance to maintain incredibly long-term stability as shown in Figure 4. The DETF sensor also doesn't require a warm-up period. Furthermore, the actual temperature coefficient of the vibrator itself is very small due to effective heat treatment. This allows the temperature detection and compensation circuit to operate efficiently. In comparison with a strain gauge load cell, a DETF sensor will have a full scale error of only 0.01% if the resistance is varied by 0.001% due to a change in temperature. A strain gauge load cell will have a full scale error of .5%. This is a significant advantage in maintaining a balance's battery life when used in remote environments.

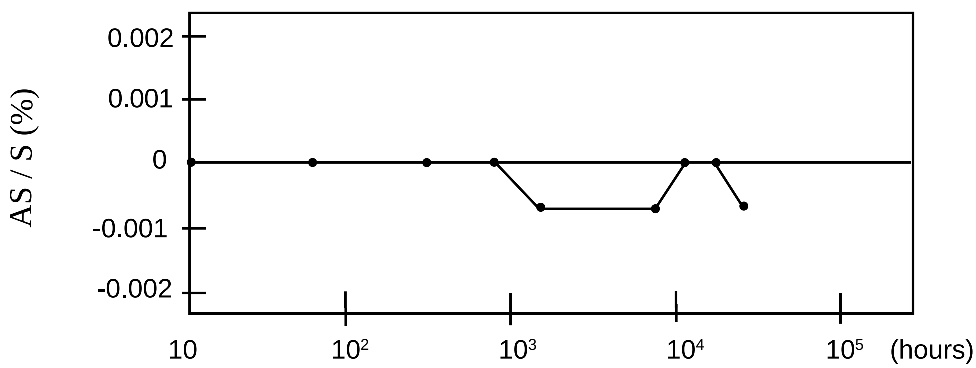


Figure 4. SPAN Drift vs. Time

Table 1 compares characteristics of the DETF sensor with a typical strain gauge load cell and a vibrating wire sensor. This data establishes the superior features of the tuning fork sensor (values of linearity and temperature are after compensation).

TABLE 1. COMPARISON OF STRAIN GAUGE, VIBRATING WIRE, & TUNING-FORK

	Resolution	Repeatability	Linearity	Hysteresis	Temperature Coefficient
Strain Gauge	50,000 counts	0.01%	0.03%	0.02%	0.01%/˚C
Vibrating Wire	150,000 counts	0.003%	0.03%	0.003%	0.001%/˚C
Tuning-Fork	500,000 counts	0.001%	0.002%	0.001%	0.0003%/˚C

5. Summary of Tuning Fork Sensor Technology

The introduction of the DETF sensor to force sensing technology clearly provides some distinct advantages over strain gauge load cells and electromagnetic force sensing systems. With its unique temperature characteristics, the DETF sensor is able provide precision and long-term stability unmatched by other force sensing technologies. Ishida manufactures three lines of balances utilizing the DETF sensor—the QB, IB, and MB Series. These balances are ideal for a wide range of applications, including weighing dyes, pharmaceuticals, jewels, and quality control for rubber and plastics. Rice Lake Weighing Systems is proud to be the sole U.S. distributor of Ishida balances featuring this amazing technology.

Ishida IB Series
- *VFD display*
- *Percent & counting modes*
- *Accumulation mode*
- *Measures in 13 units*
- *Automatic zero tracking*
- *No warm-up period required after power-up*
- *Unit conversion switching (grams to lb, etc.)*

Ishida MB Series
- *LCD display*
- *Automatic zero tracking*
- *Measures in three units: g, ct and oz (or lb)*
- *No warm-up period required after power-up*
- *Unit conversion switching (grams to lb, etc.)*

Ishida QB Series
- *LCD display*
- *Counting mode*
- *Checkweighing mode*
- *Switchable for straightweigh, piece count, over/under checkweighing modes*
- *Measures in 12 units*
- *Automatic zero tracking*
- *No warm-up period required after power-up*

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