ISA TRANSDUCER COMPENDIUM

■ Emil J. Minnar, Editor ■

ISA TRANSDUCER COMPENDIUM

1 MOTION

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THIS CHAPTER covers transducers related to motion measurements. It is subdivided into discussions of four motion measurands: displacement, velocity, acceleration, and jerk. The tabulated devices are capable of linear or angular measurements. Most of these transducers are sensitive along a single axis, but biaxial and triaxial sensors are also included.

Transducers suitable for quasi-static measurements and those suitable for measurements of vibration and shock are all discussed together, but they are tabulated separately for easier reference to a large number of types of devices.

The methods, techniques, transducers, and problems peculiar to the measurement of the four motion measurands are taken up separately. It is, of course, not possible to provide a complete survey in this short introductory chapter, but rather an attempt is made to draw attention to the main characteristics involved, with some emphasis on areas of recent instrumentation research and development.

A few of the recently-developed devices mentioned are not commercially available, and therefore not tabulated, but technical literature references are given, which show performance and construction details.

DISPLACEMENT

A measurement of displacement is basic to practically all measurements, at some stage of the instrumentation chain. Thus, for example, pressure may be measured by the displacement of a diaphragm, capsule, bellows, or piston; temperature may be measured by the displacement of a bimetallic element or of a mercury column; if the sensing element has an electrical output, such as in the case of a thermocouple or platinum thermometer, the instrumentation chain may include the displacement of a pointer, a galvanometer, or an oscilloscope trace. The devices considered here concern only the measurement of the displacement itself.

Commercially available displacement transducers include resistive, inductive, and capacitive systems as well as sensors based on a large number of physical effects.

For motions which take place very slowly, or in steps with long stationary periods, potentiometric devices have the advantages of large electrical output, availability at any desired displacement range, generally low cost, and simple associated instrumentation.

For applications requiring the measurement of strain, there are commercially available strain gages made of fine wire or foil, with many refinements such as noninductive windings; compensation for use with particular materials under conditions of changing temperature; special mounting materials and techniques to allow the measurement of strain in the plastic range, up to a strain of several percent; and dimensions from 1/16 to 6 in. long and 1/16 to 1/2 in. wide.[1] These gages are generally mounted in pairs and connected in adjacent arms of a resistance bridge for better temperature compensation and somewhat increased output.

For higher sensitivity by almost two orders of magnitude, piezoresistive strain gages have become commercially available in the past few years. At the present time, these are made of silicon with various amounts of impurity doping to improve the temperature characteristics.[2] Strains up to three parts per thousand (and, for selected devices, somewhat more) may be followed. For larger strains, adaptors are available which reduce the strain at the element.

Yet another resistive device for displacement measurements is based on the conductivity of electrolytes. It has been used commercially for phonograph pickups, as well as in horizontal-sensing angular-displacement transducers. The motion changes the cross-sectional area available to the flow of current through an electrolyte, generally increasing the area in one path and decreasing it in the other.

It may be desired to make an "absolute" rather than a relative displacement measurement, as for example in seismometers. Here, an extremely low resonant frequency is required and the mechanical spring may be further weakened by electrical feedback.[3] Since these systems have extremely small restitution forces, a noncontacting electrical sensing system is used for the best low-frequency characteristics.

The advantage of little or no friction is available in many transducers based on a measurement of the change in self-inductance, mutual inductance, electrical coupling, or capacitance, all of which require excitation from a source of alternating current. Commercially available devices include linear variable differential transformers[4] having ranges from a few hundredths of an inch to several feet. Excitation may be directly from the 60-cps, 110-V line or, for better frequency response, from carriers having frequencies from a few hundred to several thousand cycles per second. The linearity generally depends on the excitation frequency, and both are usually specified by the manufacturer.

For the highest displacement sensitivity, capacitive devices are available, but these often suffer from somewhat more complicated associated instrumentation. Thus, cylindrical capacitors with a small cylindrical air gap may be used over considerable ranges with good linearity, while parallel-plate capacitors with a spacing of 0.001 in. or less have been used[5] to measure full-scale displacements of the order of 10^{-7} in. or less.

Several other types of devices are available commercially for measuring displacement. A piezoelectric crystal or ceramic generates a charge which is very

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nearly proportional to a rapidly applied force and hence to the resulting compressional, bending, or shear displacement. If it is not required that very-low-frequency components of motion be reproduced accurately, then this charge may be measured with the help of a charge amplifier or high-impedance cathode follower or emitter follower. Piezoelectric devices have comparatively large outputs and are extensively used as phonograph pickups.

Two other devices having large outputs and, in addition, the ability to follow extremely low frequencies are the electronic displacement gage, in which an element of a vacuum tube is moved relative to the other elements by means of a linkage extending through the shell, and the capacitive "ionization transducer," in which the position of the plasma surrounding two electrodes in a gas tube is affected by the displacement of metallic rings or plates external to the tube.[6]

Other devices to measure and control displacements (generally angular, but also sometimes linear) include synchros, electrical resolvers, inductive potentiometers, and microsyns. Characteristics of these types of transducers are summarized in Reference 7.

In certain applications where a direct measurement of velocity is advantageous, an output proportional to displacement may be obtained by performing an electrical integration of the velocity output.[8] This integration is readily performed, providing the available velocity signal is sufficiently large, by means of a simple RC circuit.[9]

VELOCITY

A measurement of velocity is most readily made by means of a transducer which follows the displacement and whose output system has a response proportional to the first time derivative of the displacement, i.e., to the velocity. The most commonly used electrical devices involve the relative motion of a coil with respect to a magnetic field. It is required that the magnetic flux linking the coil change during the motion, and this may be done by having a small coil move in a nonhomogeneous magnetic field of large extent or by having a long coil and a very concentrated magnetic field. In any event, nonlinearity effects will occur unless mechanical stops are provided. For measurements of "absolute" velocity, i.e., without reference to a fixed point, a seismic mount may be used. The displacement of the mass in a spring–mass system, relative to the frame from which the spring is suspended, is equal in magnitude and opposite in direction to the absolute motion of the frame, for frequencies well above the undamped natural frequency of the spring–mass system. (See, for example, General Reference 1, pp. 310-313.) If the displacement of the mass takes place in such a way as to provide flux changes in an electrical conductor, as indicated above, then the output is proportional to velocity. Devices of this type are commonly used for vibration and shock measurements, but strict attention must be paid to the displacement limitations, the low-frequency limit due to the effects of the spring–mass system, and the high-frequency limitations due to eddy currents and loading of the velocity-meter coil itself. In applications involving large displacements, such as in the measurement of shipboard shock, the design of instruments to overcome these limitations leads to devices which are bulky and quite heavy.[10]

It is possible to overcome some of these limitations by means of a different type of velocity-measuring system involving electrical integration of the output of a piezoelectric accelerometer. The range limitation becomes the trivial one of cable length with such a system, and the low-frequency limitation is readily extended to frequencies of the order of one cycle per

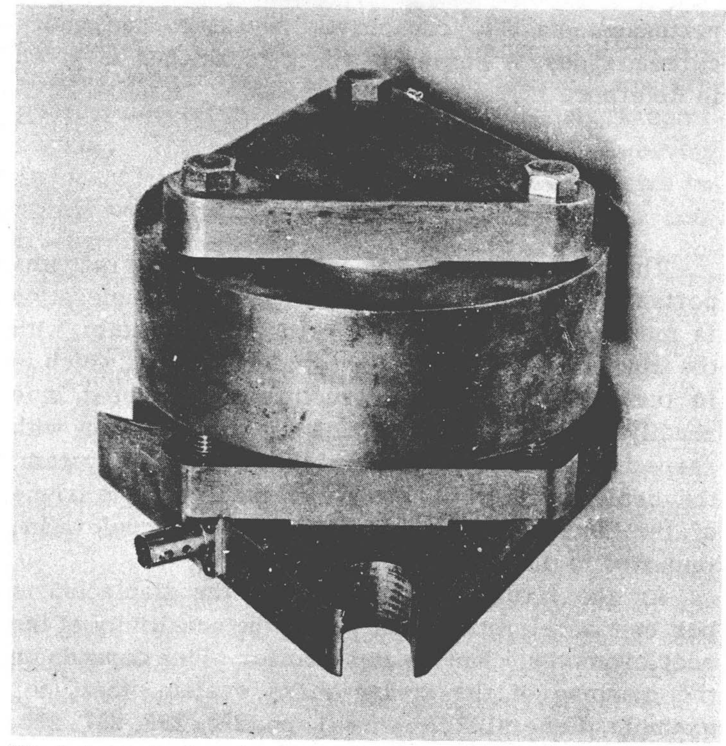

Fig. 1. Large barium titanate accelerometer for shock–velocity measurements (experimental). The edges of the triangular base are 5.6 in. long. (Courtesy of the National Bureau of Standards.)

second or less by means of an amplifier having high input impedance. In order to make possible the integration at a reasonable signal-to-noise ratio, a relatively large mass is required to load the piezoelectric element, and here again the device is likely to become bulky.[11] An experimental transducer of this type is shown in Figure 1.

A quite different type of velocity measurement is involved in the determination of rotary speed. Both analog and digital types are in use, with a wide variety of transduction principles, including AC induction,

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permanent-magnet, capacitive, reluctive, and eddy-current types. A survey of these techniques is given in Reference 12.

ACCELERATION

The measurement of acceleration is of great importance in many technologies. In general, acceleration is measured by means of a spring–mass system, with the spring fixed to the case of the instrument, which is in turn attached to the structure to be tested. It is readily shown that, for frequencies which are low with respect to the undamped natural frequency of the system, the displacement of the mass with respect to the frame of the instrument is proportional to the acceleration imparted to this frame.

As the frequency is increased, the displacement per unit acceleration, and hence the sensitivity of the accelerometer, changes in a manner which depends on the damping of the spring–mass system. (See, for example, General Reference 1 pp. 293, 295, 297, 299, and 302.) The relative displacement, x, in such a system is given by a second-order differential equation with constant coefficients, $m\ddot{x} + c\dot{x} + kx = F$, where m, c, and k are the mass, damping coefficient, and spring constant, respectively, and F is the external force applied to the system. (The dot denotes differentiation with respect to time.) The following terms are commonly used as a measure of the degree of damping:

- Damping Coefficient, c: The damping force per unit velocity, in the above differential equation.
- Damping Constant, α: The Napierian logarithm (base $e = 2.718\ldots$) of the ratio of the first to the second of two values, separated by unit time, of an exponentially decreasing quantity; $\alpha = c/2m$.
- Logarithmic Decrement, δ: The Napierian logarithm of the ratio of two successive peak amplitudes in the same direction; $\delta = 2\pi c/\sqrt{4mk - c^2}$.
- Damping Ratio, c/c_c: The ratio of the damping force per unit velocity, c, to the value $c_c = 2\sqrt{mk}$ of this force which would make the system critically damped. This ratio is often expressed as "percent of critical damping."
- Damping Factor, $e^{-\alpha t}$: The ratio of the first to the second of two values separated by time t, of an exponentially decreasing quantity having a damping constant α.
- Q: A measure of the sharpness of resonance, by analogy with electrical systems. For small damping, Q is nearly equal to the magnification at resonance. At the undamped natural frequency, $Q = (2c/c_c)^{-1}$.

The first four of these terms are related to each other, and to the angular (undamped) natural frequency $\omega_n = 2\pi f_n = \sqrt{k/m}$, as shown in Table I.

A measurement of acceleration is thus reduced to a measurement of relative displacement, and the methods available include in principle all the methods discussed in connection with displacement measurements. The most commonly used transduction principles include potentiometers, bonded and unbonded wire strain gages, devices based on changes in self-inductance, linear variable differential transformers, vibrating wires, and capacitive, piezoresistive, and piezoelectric devices. For special applications such as ballistocardiography, electrical differentiation of the output of a relative-velocity meter may also be advantageous.[8]

It is well to think in terms of two quite different types of acceleration measurements: Slowly changing and quasi-static accelerations such as are encountered in moving vehicles of all types; and vibratory and shock

Table I

Relationships Among Commonly-Used Damping Characteristics

X	$\delta = \frac{2\pi}{\omega} \frac{\alpha}{\sqrt{1 - \alpha^2/\omega^2}}$ *	$\frac{c}{c_c} = \frac{\alpha}{\omega}$
$\alpha = \frac{\delta\omega}{\sqrt{4\pi^2 + \delta^2}}$ *	X	$\frac{c}{c_c} = \frac{\delta}{\sqrt{4\pi^2 + \delta^2}}$ *
$\alpha = \omega\frac{c}{c_c}$	$\delta = \frac{2\pi c/c_c}{\sqrt{1 - (c/c_c)^2}}$ *	X

*For small damping, these relations reduce to

$$\alpha = \frac{\delta\omega}{2\pi} \quad \text{and} \quad \delta = 2\pi\frac{c}{c_c}$$

accelerations associated with machinery and explosions, and also with several biomedical phenomena. In some tests, the two types of acceleration occur simultaneously and the demands on the instrumentation may become quite severe.

Slowly changing acceleration measurements are often related to guidance or other high-accuracy functions and hence require transducers and associated instrumentation of the highest accuracy. Force-balance or "servo" types are well suited to this application. Accuracy is generally increased at the expense

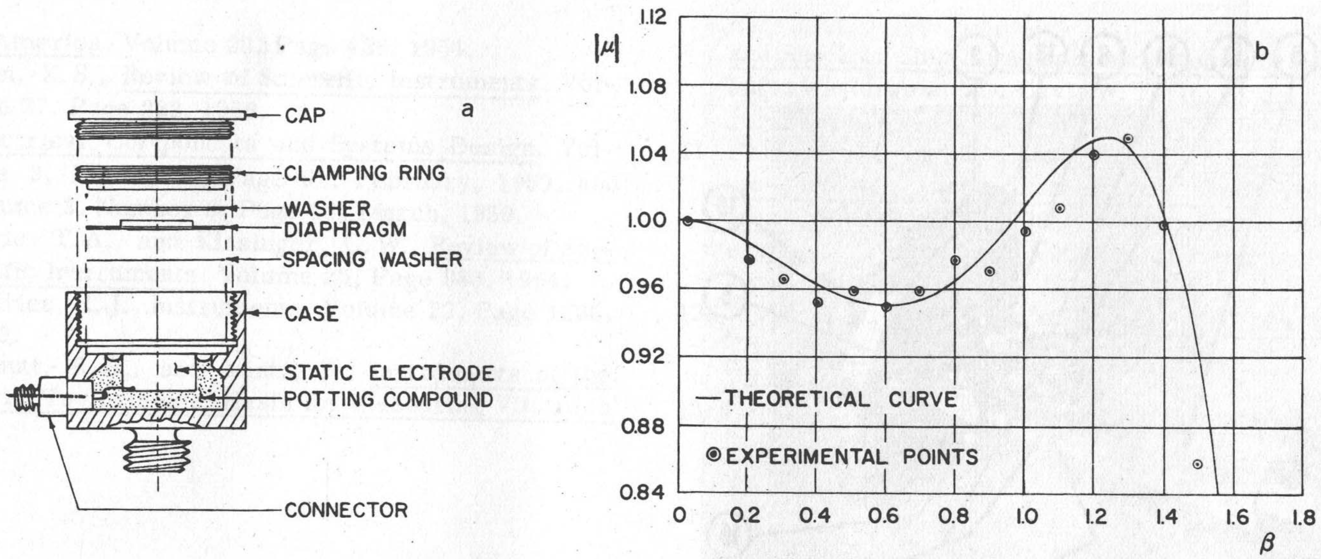

Fig. 2. Experimental capacitive accelerometer with frequency-response characteristics controlled by air damping. (a) Exploded view. (b) Theoretical and measured frequency-response of 2500-cps accelerometer. $|\mu|$ is the magnitude of the dynamic amplitude ratio, β the frequency ratio f/f_0, where f_0 is the natural frequency of the evacuated transducer. (From Ref. 15, by permission of the Journal of the Acoustical Society of America.)

of high-frequency response and ability to withstand large shocks.

On the other hand, measurements of vibration and shock generally do not require an accuracy better than 5, 10, or even 20%, in view of the large range of vibration and shock amplitudes at different points of a structure or vehicle, particularly for frequency components above a few hundred cycles per second. The requirements for accelerometers suitable for vibration and shock measurements generally include a high resonant frequency; extremely rugged construction free of subsidiary resonances; very low response to accelerations at right angles to the sensitive axis; a mass which is negligible with respect to the structure to be tested; small temperature effects; small sensitivity to sound and to ambient pressure changes; and low output from motions of the connecting cable.[13] These characteristics may be achieved in a number of designs of piezoelectric accelerometers,[14] but nearly always at the expense of the ability to follow very-low-frequency acceleration changes.

It is seen that the measurements of the two types of accelerations are fundamentally incompatible and considerable sacrifices in the fundamental requirements for both types of measurements have to be made in order to use a single instrument. Thus, it is common practice in missile technology, for example, to use separate devices for the two types of acceleration measurements. Since these devices generally have different masses and cannot be mounted at the identical position, the records may not agree in the range of frequencies which should be reproduced correctly by both devices. Considerable effort has been made to develop accelerometers having compromise specifications which make them suitable for both low-frequency accelerations and vibration and shock applications. These include wire strain-gage types having resonant frequencies above 1500 cps, and capacitive devices with frequency-response characteristics controlled by air damping[15] (see Figure 2). As another solution to this problem, acceleration transducers with piezoresistive strain elements to sense the displacement of the inertial mass have recently become available from several commercial sources.

JERK

The characteristic of motion which is of interest under conditions of rapidly changing forces is sometimes the time rate of change of acceleration, or jerk. As indicated by the above definition, jerk is expressed in *g* per second, cm/sec^3, or ft/sec^3. The major applications for jerk measurements have been in connection with physiological measurements, where it appears that discomfort and injuries from transient motions correlate well with the measured jerk, and also with ballistocardiographic measurements,[16] in which considerable additional detail is brought out by the time differentiation of the more usual velocity or acceleration traces.

An output proportional to jerk is readily obtained by electrical differentiation of the output from any accelerometer. This process is particularly simple for piezoelectric accelerometers, since these devices represent capacitive sources which only require a resistive load to perform the required differentiation. An experimental piezoelectric jerkmeter is shown in Figure 3.

Another simple jerk-measuring system consists of a permanent magnet acting as a spring in a spring–mass

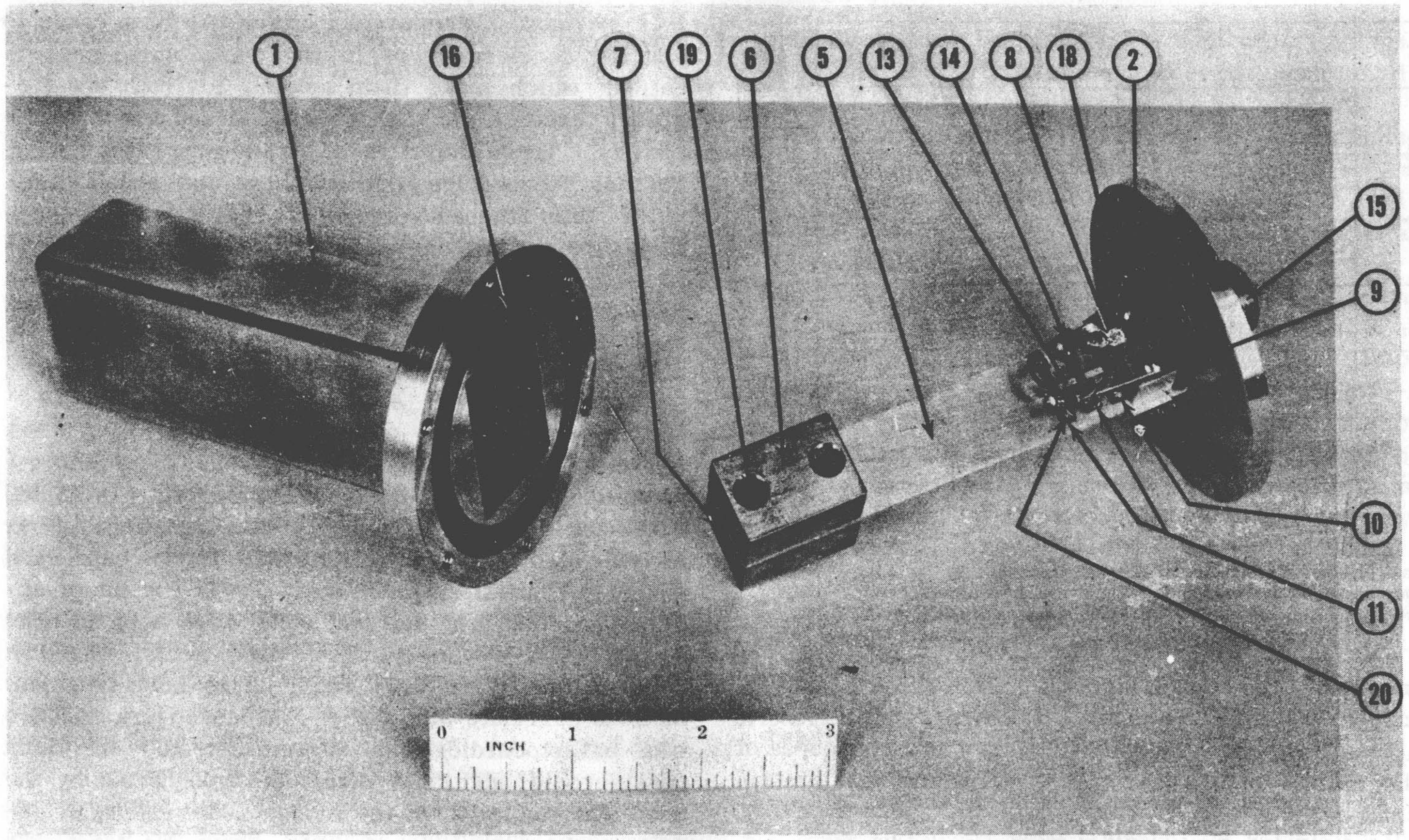

Fig. 3. An experimental jerkmeter. Numbers refer to parts described in Ref. 16; (1) Case. (2) Cover and clamp base. (5) Connector. (6, 7, 19) Loading-mass assembly. (8) Clamping block. (9) Solder lug. (10, 11) Clamping straps. (13) Barium titanate element. (14) Differentiating load resistor; (15) Output connector. (16) O-ring. (From Ref. 16, courtesy of the National Bureau of Standards and the Review of Scientific Instruments.)

system, with a coil located so as to produce an output proportional to the rate of change of magnetic flux due to both the magnetostrictive effect and the motion of the pole with respect to the pickup coil.

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ISA TRANSDUCER COMPENDIUM QUESTIONNAIRE
MOTION

Manufacturer ____________________

Address ____________________

City, Zone & State ____________________

Submitted by ____________________ Co. Position ____________________

This questionnaire will provide data on transducers measuring MOTION (Displacement, Velocity, Acceleration, Vibration, and Shock) as marketed by your company. Please complete one questionnaire for each model series of transducers. Do not prepare a questionnaire for each transducer in a model series.

To insure uniform presentation of data for this Compendium, answer the questions listed below in accordance with performance terms defined in the terminology reference insert (green sheet). All questions must be completed, specifying proper units wherever possible. If certain questions do not apply, or if data are not available, indicate in proper blank – "Not Applicable" or, "Not Available". Be sure data are correct and legible. Instrument Society of America will not be responsible for the accuracy of the data submitted by the manufacturer for use in the Transducer Compendium.

DO NOT ATTEMPT TO COMPLETE THIS QUESTIONNAIRE WITHOUT FIRST READING ABOVE INSTRUCTIONS AND TERMINOLOGY SHEET THOROUGHLY.

1. **NUMBER** Do not answer ____________________
   (Reference Code Number to be designated by ISA.)

2. **MANUFACTURER CODE NUMBER** Do not answer ____________________
   (To be designated by ISA.)

3. **MODEL SERIES** ____________________ **NO. OF TRANSDUCERS IN MODEL SERIES** ____________________
   (Manufacturer's designation for the model series - indicate the number of individual transducers in this series.)

4. **MEASURAND** (The physical quantity, property, or condition measured.)

FOR DISPLACEMENT, VELOCITY, AND ACCELERATION:

Classification

( ) Displacement
( ) Velocity
( ) Acceleration
( ) ____________ (Please Specify)

Type

( ) Linear
( ) Angular
( ) ____________ (Please Specify)

( ) Uniaxial
( ) Biaxial
( ) Triaxial

FOR VIBRATION AND SHOCK:

( ) Shock
( ) Vibration
  ( ) uniaxial ( ) sinusoidal
  ( ) biaxial ( ) random
  ( ) triaxial ( ) ____________ (Please Specify)
( ) Other ____________ (Please Specify)

Measurand Characteristic

( ) Amplitude
( ) frequency
( ) acceleration
( ) jerk
( ) other ____________ (please specify)

5. a - **MEASURAND RANGE** (Minimum and maximum values of the measurand which can be measured by the transducer. Please specify units.) ____________________

b - **MEASURAND PROPERTIES** (The inherent properties of the measurand which must be maintained while a transducer operates within the specified range. List minimum and maximum values of these properties. These are not to be confused with environmental characteristics.)

Measurand Impedance ____________ Resonant Frequency ________ cps

Power Drain ____________

Measurand Limitations ____________________

6. **OPERATING PRINCIPLE** (The nature of the sensing technique and the transduction principle necessary to sense the measurand and produce an output signal.)

FOR DISPLACEMENT, VELOCITY, AND ACCELERATION:

Mechanical Linkage

( ) spring-mass
( ) pendulous
( ) contra-rotating weights
( ) cable
( ) self-aligning shaft
( ) vibrating string
( ) ____________ (Please Specify)

Transduction Principles

( ) electromagnetic self-generating
( ) piezoelectric
( ) differential transformer
( ) variable reluctance
( ) potentiometric
( ) capacitance
( ) inductance
( ) strain gage
( ) resistive
( ) magnetostrictive
( ) photoelectric
( ) switch
( ) ____________ (Please Specify)

Special Characteristics

( ) air damped
( ) gas damped
( ) oil damped
( ) magnetically damped
( ) hermetically sealed
( ) ____________ (Please Specify)

FOR VIBRATION AND SHOCK:

( ) Strain gage
( ) Magnetostrictive
( ) Mutual Inductance

( ) Capacitance
( ) Potentiometric
( ) Resistance

( ) Electromagnetic self-generating
( ) Pendulum
( ) Piezoelectric
( ) Other ____________ (Please Specify)

7. **OUTPUT CHARACTERISTICS** (The nature of the output signal; output range(s); power output; output impedance.)

   Nature ____________ Power Output ____________

   Output Range(s) ____________ Output Impedance ____________

8. **SENSITIVITY** (The ratio of full-scale output to full-scale measurand value. Identify units clearly.) ____________

9. **EXCITATION** (The nature and magnitude of all external energy required for proper transducer operation; this, of course, excludes the measurand. Identify units and specifications clearly.) ____________

10. **THEORETICAL TRANSFER FUNCTION** (The theoretical relation between measurand and output values as determined by inherent principles of operation.)

    ( ) linear ( ) logarithmic ( ) error function
    ( ) quadratic ( ) sinusoidal ( ) other ____________ (Specify)

11. **STATIC ERROR BAND** (The deviation from the theoretical transfer function under constant environmental conditions. This of course includes effects of hysterisis, friction and repeatability, as well as other sources of error which are not due to environmental variations.)

    Portion of Range (% of full-scale measurand)

    from ________ to ________

    Maximum Static Error (% of full-scale output)

    ____

    Environmental Conditions ____________________

12. **REPEATABILITY** (The ability of a transducer to reproduce an output signal when the same measurand value is applied to it three successive times under the same conditions and direction. Expressed as the maximum difference between output readings in terms of percent of full-scale output.)

Portion of Range (% of full-scale measurand)	Repeatability (% of full-scale output)
from ______ to ______	______

Environmental Conditions ______

13. **RESOLUTION** (The smallest change of measurand that produces a recognizable change in output, expressed as percent of full-scale measurand.)

Portion of Range (% of full-scale measurand)	Resolution (% of full-scale measurand)
from ______ to ______	______

Environmental Conditions ______

14. a - **OVERRANGE FACTOR** (The maximum magnitude of measurand that can be applied to a transducer without causing a change in performance beyond specified tolerances, expressed as percent of full-scale measurand.) ______

b - **LIFE EXPECTANCY** (The transducer life in terms of full-scale cycles, or exposure time under operating conditions, before the transducer performance exceeds static error band limits.) ______

15. **TIME CONSTANT** (The time required for the transducer output to reach 63% of its final output value as a result of a step change in the measurand.) ______

16. **CALIBRATION AND ZERO ADJUSTMENT** (Does the transducer have an internal calibration or zero adjustment?)

______

(Is it a relative or absolute method?)

______

17. a - **ENVIRONMENTAL RANGES** (The range of environmental conditions under which a transducer will perform.)

b - **ENVIRONMENTAL EFFECTS** (The change in output due to a change in the environmental conditions. Expressed as the zero and sensitivity shift per unit of environmental change.)

Environmental Condition	a - Range	b - Zero Shift (% of full-scale output per unit change)	Sensitivity Shift (% of sensitivity per unit change)
Temperature	______ F	______ %/F	______ %/F
Pressure	______ psi	______ %/psi	______ %/psi
Humidity	______ %R.H.	______ %/%R.H.	______ %/%R.H.
Acceleration	______ g.	______ %/g.	______ %/g.
Shock	______ g. for ______ m sec.	______ %/g.	______ %/g.
Vibration	______ g. at ______ cps	______ %/g.	______ %/g.
Magnetic Field	______ oersteds	______ %/oersteds	______ %/oersteds
Electric Field	______ esu	______ %/esu	______ %/esu

18. **SIZE, WEIGHT AND MOUNTING** (The physical dimensions, weight and mounting specifications of the entire apparatus between measurand and output.)

Size ______ Weight ______

Mounting ______

19. **IS THIS MODEL OR SERIES TRANSDUCER AVAILABLE TO PURCHASERS OUTSIDE U.S.?** Yes ______

No ______

If "YES" please indicate market areas:

( ) Latin America ( ) European Common Market ( ) Japan
( ) Canada ( ) British Market ( ) others ______ (Please Specify)

20. **IS THE MODEL OR SERIES TRANSDUCER LICENSED TO FOREIGN MANUFACTURERS?** Yes ______

No ______

If so, please give name of manufacturers and indicate how identified:

Foreign manufacturer	Model No.
______	______
______	______
______	______

21. **REMARKS** (Any special characteristics of the transducer, such as isolation, damping properties, bearing material, electrical noise level, etc., which should be noted.)

______

______

Special Inherent Damping Characteristics ______

Is this transducer specifically designed for:

( ) Aero/Space ( ) Biomedical ( ) Marine Sciences ( ) None of these

UPON COMPLETION AND APPROVAL OF YOUR PRODUCT DATA, PLEASE RETURN THIS QUESTIONNAIRE TO

ISA TRANSDUCER COMPENDIUM
Penn Sheraton Hotel
530 William Penn Place
Pittsburgh 19, Pa.

NO LATER THAN

A POSTAGE-PAID RETURN ENVELOPE HAS BEEN PROVIDED FOR THIS PURPOSE.

MOTION

ISA NUMBER	MFR.	MODEL SERIES Series Identification Number of Transducers in Series	MEASURAND	MEASURAND RANGE	MEASURAND PROPERTIES Measurand Impedance Resonant Frequency Power Drain Measurand Limitations	OPERATING PRINCIPLE Mechanical Linkage Transduction Principle Special Characteristics	OUTPUT CHARACTERISTICS Nature Output Range(s) Power Output Output Impedance	SENSITIVITY	EXCITATION	THEORETICAL TRANSFER FUNCTION	STATIC ERROR BAND Portion of Range (% of full-scale measurand) Environmental Conditions	STATIC ERROR BAND Maximum Static Error (% of full-scale output)
Displacement, Linear												
1-001	55	CM 500-A 2	Position: linear	0.060 in.	Not available — — —	Direct Resistive Silicone damped	Electrical — — —		Direct mechanical equivalent of 5 oz static	'AND' logic	0 to 100%	None (sensor is self-compensating against position error)
1-002	20	LMT 150	Displacement: linear	±0.005 to ±60 in.	Not available — — —	Self-aligning shaft Differential transformer —	Electrical 1 to 3 V rms 1 to 20 mW < 300 Ω	2 to 200 V (rms)/in.	5 to 120 V (rms) 60 to 50,000 cps	Linear	0 to 100% −300 to +750 F	0.5%
1-003	20	SS 18	Displacement: linear	±0.050 to ±2.0 in. stroke	Not available — — —	Self-aligning shaft Differential transformer Solid state converter/demodulator	Direct current 1.5 to 27 V 1 mW 3000 to 7000 Ω	2.5 to 240 V/in.	Either 6 V DC or 24 V DC	Linear	0 to 100% Room temperature	1.0%
1-004	63	1500 8	Displacement: linear	2 to 180 in.	Not available — — —	Cable Potentiometric —	Electrical 0 to 15 V — 0 to 500 Ω, variable	6.5 to 270 mV/V per in.	15 V max	Linear	0 to 100% STP	0.1%
1-005	36	Mechohm 2	Displacement: linear	0 to 0.120 in. 0 to 0.200 in.	— Operating force varies from 30 gm at threshold to 70 gm at max output (special low-force units are available) —	Actuator lever Resistive —	Stepless resistance changes 120 or 240 W —	Not available	115 V, 50 or 60 cps, 60 ma	Specified by customer	0 to 100%	0.7%
1-006	95	1120 —	Displacement: linear (uniaxial)	Min:0 to 0.1 in. Max:0 to 120 in.	Not available — — —	Self-aligning shaft Potentiometric Available with dust seal	Resistance-ratio 0 to 100 mV or 0 to 100 μa — —	0.8 to 1000 mV/in. 0.8 to 1000 μa/in.	With potentiometer no excitation needed; with power unit (#1210) 115 V, 60 cps; or 24 V DC, 10 W	Linear	0 to 100%	0.1%

REPEATABILITY: Portion of Range (% of full-scale measurand) — Environmental Conditions	REPEATABILITY: Repeatability (% of full-scale output)	RESOLUTION: Portion of Range (% of full-scale measurand) — Environmental Conditions	RESOLUTION: Resolution (% of full-scale measurand)	OVERRANGE FACTOR	LIFE EXPECTANCY	TIME CONSTANT	CALIBRATION AND ZERO ADJUSTMENT: Internal Calibration and Zero Adjustment Relative or Absolute	ENVIRONMENTAL RANGES AND EFFECTS: Range	ENVIRONMENTAL RANGES AND EFFECTS: Zero Shift (% of full-scale output/unit change)	ENVIRONMENTAL RANGES AND EFFECTS: Sensitivity Shift (% of sensitivity/unit change)	SIZE, WEIGHT, AND MOUNTING	REMARKS: Special Characteristics, Damping Characteristics, Special Designs, Foreign Availability, Foreign Manufacturer Reference Number	ISA NUMBER
0 to 100% Standard	0%			120%	Field units still operating after 5 x 10^7 cycles	Not available	Nonadjustable —	50 to 250 F			0.500" O.D. x 1.062" long 0.6 oz Direct mounting	Completely self-compensating against all physical changes within its range such as dimensional, temperature, acceleration, static position, etc. Silicone damped Aero/space Available in Canada, Europe, and Japan F-1066	1-001
0 to 100%	0.1%	0 to 100%	Infinite	110%	10^7 cycles	Depends on carrier frequency		-300 to +750 F 0 to 10,000 psi 0 to 100% R.H. 0 to 50 g 15 g for 11 msec 20 g at 1000 cps	0.005%/F 0.0001%/psi No effect 0.001%/g 0.001%/g 0.001%/g	0.015%/F 0.0001%/psi 0.001%/g 0.001%/g 0.001%/g	½" to 12' in length, ⅜" to 1½" in dia 1 oz to 25 lb	Exceptionally large stroke-to-length ratio — Aero/space Available in Europe and the Americas —	1-002
0 to 100%	0.1%	0 to 100%	Infinite	110%	5000 hr	0.1 to 20 msec		-65 to +250 F	0.005%/F	0.015%/F	0.8" to 8.0" x ¾" dia 1 to 8 oz Clamp mounting	Output ripple less than 3% F.S. (rms) — Aero/space Available in Europe and the Americas —	1-003
0 to 100% STP	0.1%	0 to 100% STP	Infinite	None, 100% positive stop engages at rated travel	Not available	Not available	None —	-10 to +180 F 40 g max 12 g at 10 to 2000 cps	 0.06%/g		5" x 8" x 6" (180" unit), 6" x 4½" x 3" (150" unit) 3 lb 6 oz (180" unit), 2 lb (150" unit) Flange mounting	— — — Generally available worldwide —	1-004
0 to 100%	1.0%	0 to 100%	Infinite	125%	50,000 hr in excess of 3 x 10^8 cycles	< 50 msec	None —	-65 to +70 C 14.7 psi 98% R.H.	Not available	Not available	3" x 2" x 2" (plus external resistors) 34 or 40 oz	— — — Generally available worldwide —	1-005
0 to 100%	0.05%	0.0005 to 0.0015 in. depending on range and resistance		To specification for requirement	10^7 cycles	Direct coupled – no delay	Yes —	Designed for industrial and ground-support environments			1" to 2" dia x stroke length < 1 lb	— — Available in Europe, Canada, and Africa —	1-006

MOTION

ISA NUMBER	MFR.	MODEL SERIES Series Identification Number of Transducers in Series	MEASURAND	MEASURAND RANGE	MEASURAND PROPERTIES Measurand Impedance Resonant Frequency Power Drain Measurand Limitations	OPERATING PRINCIPLE Mechanical Linkage Transduction Principle Special Characteristics	OUTPUT CHARACTERISTICS Nature Output Range(s) Power Output Output Impedance	SENSITIVITY	EXCITATION	THEORETICAL TRANSFER FUNCTION	STATIC ERROR BAND Portion of Range (% of full-scale measurand)	Maximum Static Error (% of full-scale output) Environmental Conditions
1-007	47	Microtrans 1	Displacement: linear (uniaxial)	0.25 to 1 in.	Not available — — —	Self-aligning shaft Spring-pneumatic bellows —	Pneumatic pressure 0 to 30 psig — —	120 psi/in.	35 psig air supply (regulated)	Linear	10 to 100%	1.0% STP
1-008	33	131 To suit requirements	Displacement: linear (uniaxial)	±0.200 in.	— — 0.5 W —	Self-aligning shaft Differential transformer Differential transformer with spring-loaded prod	AC voltage 0 to 20 V 20 mW 2 K	0 to 28 V per 0.150 in.	400 cps, voltage to suit requirements	Linear	0 to 100%	0.5%
1-009	33	220 To suit requirements	Displacement: linear (uniaxial)	0.00001 to ±0.250 in. Up to ±2 in. on special order	— — 0.5 W	— Differential transformer —	AC voltage 0 to 75 V 20 mW To specification	700 V/in.	0 to 115 V at 400 cps	Linear	0 to 100%	0.025%
1-010	200	CE-10 24	Displacement: linear (biaxial)	±0.005 to +5.0 in.	— High cps 1 W max —	— Differential transformer Hermetically sealed	Voltage Millivolts to volts Milliwatts to 1 W 10 to 100 K	MV/mil to 50 V/in.	AC voltage, 60 to 20 Kcps carrier frequency	Linear	0 to 100%	0.1 to 0.5%
1-011	59	BC 6	Displacement: linear (uniaxial)	Min: ±0.20 in. Max: ±0.175 in.	100 K 7.3 to 23 cps 0.62 to 2.0(in.-lb) x (frequency) Direction normal to axis of beam	Spring-mass Strain gage (semiconductor) —	Electric ±1 V DC min F.S. — 1 K	6 to 50 V/in.	20 V DC or AC (rms)	Linear	0 to 100%	0.85% -10 to +150 F
1-012	96	VGB 12 1	Displacement: linear (uniaxial)	0 to 0.25 in.	— 5000 cps Less than 1 grain Must posess correct magnetic characteristics	No mechanical linkage Differential transformer Hermetically sealed	AC amplitude 20 to 10,000 mV 0 to 100 mW 100 Ω max	200 mV per 0.0001 in.	110 V, 60 cps or other AC voltage	Error function	0 to 100%	0.1% Standard
1-013	91	402 10	Displacement: linear	0.5 to 12 in. travel	— — — 20 in./sec max shaft velocity	Self-aligning shaft Potentiometric Environmentally sealed	Electrical 0 to 100% of V_{exc} 1 W/in. electrical travel at 70 F 1, 2, 5, 7.5, 10, 20 K		AC or DC power supply	Linear	0 to 2% 2 to 98% 98 to 100%	1.0% 0.5% 1.0% Room conditions

REPEATABILITY: Portion of Range (% of full-scale measurand)	REPEATABILITY: Repeatability (% of full-scale output)	RESOLUTION: Portion of Range (% of full-scale measurand)	RESOLUTION: Resolution (% of full-scale measurand)	OVERRANGE FACTOR	LIFE EXPECTANCY	TIME CONSTANT	CALIBRATION AND ZERO ADJUSTMENT: Internal Calibration and Zero Adjustment Relative or Absolute	ENVIRONMENTAL RANGES AND EFFECTS: Range	ENVIRONMENTAL RANGES AND EFFECTS: Zero Shift (% of full-scale output/unit change)	ENVIRONMENTAL RANGES AND EFFECTS: Sensitivity Shift (% of sensitivity/unit change)	SIZE, WEIGHT, AND MOUNTING	REMARKS: Special Characteristics, Damping Characteristics, Special Designs, Foreign Availability, Foreign Manufacturer Reference Number	ISA NUMBER
Environmental Conditions		Environmental Conditions											
Not available		Not available		Not available	Not available	Not available	Yes Relative	14.7 psi	1/30%/psi	0%/psi	7½" x 6½" x 4½" 10 lb Bolt mounted, in any position for contact	Usual application is to measure expansion of turbine casing during start-up — — Generally available world-wide F-1003, F-1004	1-007
0 to 100%	0.5%	0 to 100%	10 μin.	150%	10^6 cycles	Not available	None	-65 to +185 F 15 to 0 psi 100% R.H. 100 g 100 g for 11 msec 100 g at 2000 cps	0.01%/F	0.01%/F	1" x 4 5/16" 4½ oz	— Aero/space, biomedical Generally available world-wide —	1-008
0 to 100%	0.02%	0 to 100%	0.002%	200%	Indefinite – no rubbing parts	Not available		-65 to +200 F 50 to 0 psi 100% R.H. 100 g 100 g for 11 msec 100 g at 2 Kcps	0.01%/F	0.01%/F	2 oz 2 holes in mounting flange	— — Aero/space, biomedical Generally available world-wide —	1-009
0 to 100%	0.05%	0 to 100%	0.01%	Varies up to 200%	Unlimited (static device)	Depends on excitation frequency	None	350 F 100% R.H. 15 g 150 g for 1.0 msec 20 g to 2000 cps	0.01%/F 0%/% R.H. 0%/g 0%/g 0%/g	0.01%/F 0%/% R.H.	¼" dia to 1½" dia x ⅜" to 10" Varies Varies	— — Aero/space Generally available world-wide —	1-010
0 to 100% -10 to +150 F	±0.1%	0 to 100% -10 to +150 F	Infinite	200%	3 to 5 x 10^6 duty cycles	2160 msec to 6980 μsec	None	-10 to +150 F	< 0.005%/F		1½" x 4¼" x 1" to 1⅜" x 6¼" x 1 3/16" Approx. ½ oz Screw, loads applied through ball	— — Aero/space, biomedical, and marine sciences Available in Latin America, Canada, European Common Market, and Japan —	1-011
0 to 100% Standard	0.1%	0 to 100%	0.1%	100 to 125%	> 10^4 hr	< 1 msec	Yes Relative	-65 to +150 F 0 psi 0 to 100% R.H. 50 g 50 g at 2 to 2000 cps	0%/F 0%/psi 0%/% R.H. 0%/g	0%/F 0%/psi 0%/% R.H. 0%/g	2 piece, ¾" O.D. x 2" plus 1 piece 3" x 3" x 5" 2 lb Pickoff mounting in ⅝"-18 UNF holes, electronics: bolt down	Null ripple – max — — Generally available world-wide —	1-012
0 to 100% Room conditions	0.1 to 0.2% (±1 wire)	0 to 100% Room conditions	0.1 to 0.2% (depending on travel and resistance)	100%	10^6 in. total stroke	Not available		-65 to +275 F 0 to 15 psi 100% R.H. (100 hr) 100 g 100 g for 8 msec 50 g at 2000 cps	0.01%/F* 0%/psi* 0%/% R.H.* max 0.1%/g* max 0.2%/g* max 0.3%/g*	0%/F. 0%/psi 0%/% R.H. 0%/g 0%/g 0%/g	¾" dia, 2⅞" length, plus mechanical travel Approx. 1 oz/in. Body threads or optional brackets	Double 0-ring seals on shaft, single or dual output, switches available. Shaft rotates 360° — Aero/space Available in Canada and Europe —	1-013

*Errors are not zero shift, but ± environmental errors – zero shift is 0%.

MOTION

ISA NUMBER	MFR.	MODEL SERIES Series Identification Number of Transducers in Series	MEASURAND	MEASURAND RANGE	MEASURAND PROPERTIES Measurand Impedance Resonant Frequency Power Drain Measurand Limitations	OPERATING PRINCIPLE Mechanical Linkage Transduction Principle Special Characteristics	OUTPUT CHARACTERISTICS Nature Output Range(s) Power Output Output Impedance	SENSITIVITY	EXCITATION	THEORETICAL TRANSFER FUNCTION	STATIC ERROR BAND: Portion of Range (% of full-scale measurand)	STATIC ERROR BAND: Maximum Static Error (% of full-scale output)
											Environmental Conditions	
1-014	91	403 18	Displacement: linear	0.5 to 6 in. travel	— — — 20 in./sec max shaft velocity	Self-aligning shaft Potentiometric Environmentally sealed	Electrical 0 to 100% of Vexc 1 W/in. electrical travel at 70 F 1, 2, 5, 7.5, 10, 20 K		AC or DC	Linear	0 to 2% 2 to 98% 98 to 100% Room conditions	1.0% 0.5% 1.0%
1-015	146	51D05 100	Displacement: linear	0 to 7 cm	— — — Must be capable of moving the sensing element (weight 0.009 Kg)	Self-aligning shaft Capacitance —	Change of capacitance 0 to 1 and 0 to 7 pF — 11 and 19 pF	1 pF/cm and 1/7 pF/cm	DISA reactance converter 51BOZ with accessories	Linear	0 to 100% STP	0.2% ± 0.001 cm
1-016	146	PU 3a 500	Displacement: linear	0.0001 to 0.5 cm	— — None Must be conductive material	— Capacitance —	Change of capacitance 0 to 1 pF — 15 pF		DISA reactance converter 51BOZ with accessories	Hyperbolic	0 to 100%	1%
1-017	157	DT-500, DT-1000, DT-2000 3	Displacement: linear	0.00025 to 0.5 in. 0.00050 to 1.0 in. 0.001 to 2.0 in.		Self-aligning shaft — —	Voltage 0 to 10 V — 2.5 K	10 V/F.S.	RF excitation from a dynagage system	Linear	0 to 100% 70 F	1%
1-018	157	PT-3, PT-4, PT-5 3	Displacement: linear	0.000001 to 1.0 in.		— Capacitance —	Voltage 0 to 10 V — 1.5 K	10 V/F.S. transducer; 1 µin. dependent upon initial air gap and electrode configuration	A dynagage measuring system	Linear		

REPEATABILITY: Portion of Range (% of full-scale measurand)	REPEATABILITY: Repeatability (% of full-scale output)	REPEATABILITY: Environmental Conditions	RESOLUTION: Portion of Range (% of full-scale measurand)	RESOLUTION: Resolution (% of full-scale measurand)	RESOLUTION: Environmental Conditions	OVERRANGE FACTOR	LIFE EXPECTANCY	TIME CONSTANT	CALIBRATION AND ZERO ADJUSTMENT: Internal Calibration and Zero Adjustment Relative or Absolute	ENVIRONMENTAL RANGES AND EFFECTS: Range	ENVIRONMENTAL RANGES AND EFFECTS: Zero Shift (% of full-scale output/unit change)	ENVIRONMENTAL RANGES AND EFFECTS: Sensitivity Shift (% of sensitivity/unit change)	SIZE, WEIGHT, AND MOUNTING	REMARKS: Special Characteristics, Damping Characteristics, Special Designs, Foreign Availability, Foreign Manufacturer Reference Number	ISA NUMBER
0 to 100%	0.1 to 0.2% (±1 wire)	Room conditions	0 to 100%	0.1 to 0.2% (depends on travel and resistance)	Room conditions	100%	10^6 in. total stroke	Not available	None —	-65 to +275 F 0 to 15 psi 100% R.H. (100 hr) 100 g 100 g for 8 msec 25 g at 2000 cps *Errors are not zero shift, but ± environmental errors – zero shift is 0%.	0.01%/F* 0%/psi* 0%/% R.H.* max 0.1%* max 0.2%* max 0.3%*	0%/F 0%/psi 0%/% R.H. 0%/g 0%/g 0%/g	½" dia x 1.875" plus mechanical travel Approx. 1 oz/in.	Double 0-rings sealed against humidity contamination. Single or dual output stainless or aluminum case. Transmitting shaft rotates 360°. Switches available. — Aero/space Available in Canada and Europe —	1-014
0 to 100%	0.1%	STP	0 to 100%	0.1%	STP	115%	10^7 cycles	40 μsec	None —	-50 to +200 F	0.06%/F	0.003%/F	27 mm dia x 130 mm 0.2 Kg (without accessories) End clamp mounting	— — Generally available world-wide F-1023	1-015
								40 μsec	None —	-50 to +200 F	0.1%/F	0.1%/F	3 mm dia x 62 mm 0.210 Kg End clamp mounting	— — Generally available world-wide F-1023	1-016
0 to 100%	1%	70 F	0 to 100%	0.01%	70 F	105%	Unknown	~15 μsec		225 F 100% R.H.	0.2%/F 0%/% R.H.	0.05%/F 0%/% R.H.	4½ to 6¼ oz	A dynagage measuring system is required for use with these transducers. All specifications apply to the dynagage-transducer combination. — — — —	1-017
0 to 100%	1%		0 to 100%	0.01%			Unknown	10 μsec		200 F 100% R.H. 100 g at 1000 cps	0.25%/F 0%/% R.H. 0.05%/g	0.05%/F 0%/% R.H.	2 to 15 oz ¾"-40 threads	A dynagage measuring system is required for use with these transducers. All specifications apply to the dynagage-transducer combination — — — —	1-018

MOTION

ISA NUMBER	MFR.	MODEL SERIES Series Identification Number of Transducers in Series	MEASURAND	MEASURAND RANGE	MEASURAND PROPERTIES Measurand Impedance Resonant Frequency Power Drain Measurand Limitations	OPERATING PRINCIPLE Mechanical Linkage Transduction Principle Special Characteristics	OUTPUT CHARACTERISTICS Nature Output Range(s) Power Output Output Impedance	SENSITIVITY	EXCITATION	THEORETICAL TRANSFER FUNCTION	STATIC ERROR BAND: Portion of Range (% of full-scale measurand)	STATIC ERROR BAND: Maximum Static Error (% of full-scale output) Environmental Conditions
1-019	15	108 3	Displacement: linear	0–0.5 to 0–6 in.	Not available Not available 2.5 W/in. range 0 to 30 in./sec	Shaft Potentiometric ——	Potentiometer Not available Not available 1 to 50 K	1/1	Any AC or DC voltage not exceeding rated power	Linear	0 to 100%	Independent linearity 0.5 to 0.75% Room
1-020	15	128 2	Displacement: linear	0–8 to 0–24 in.	Not available Not available 2.5 W/in. range 0 to 30 in./sec	Self-aligning shaft Potentiometric ——	Potentiometer Not available Not available 0.5 to 20 K per in. range	1/1	Any AC or DC voltage not exceeding rated power	Linear	0 to 100%	Independent linearity 0.2% Room
1-021	15	141 1	Displacement: linear	0–3/16 to 0–7/16 in.	Not available Not available 0.8 W at 158 F max 0 to 30 in./sec	Shaft Potentiometric ——	Potentiometer Not available Not available 0.5 to 10 K	1/1	Any AC or DC voltage not exceeding rated power	Linear	0 to 100%	Independent linearity 1.0% Room
1-022	15	147 1	Displacement: linear	0 to 9 in. (other ranges possible)	Not available Not available 0.1 W at 500 F max 0 to 10 in./sec	Self-aligning shaft Potentiometric ——	Potentiometer Not available Not available 5 K (others possible)	1/1	Any AC or DC voltage not exceeding rated power	Linear	0 to 100%	Independent linearity 0.25% Room
1-023	15	150 1	Displacement: linear	0–0.015 to 0–0.070 in.	Not available Not available 0.1 W at 400 F max 0 to 30 in./sec	Spring loaded shaft Potentiometric ——	Potentiometer Not available Not available 0.5 to 5 K	1/1	Any AC or DC voltage not exceeding power rating	Linear	2 to 98%	2.0% Room