Instruction Manual

High Temperature Pressure Measuring Systems

KP-1911 and KP-2025 Series

KAMAN

PART NO: 860089-001
Rev. B

HIGH TEMPERATURE PRESSURE MEASURING SYSTEMS

KP-1911 AND KP-2025 SERIES

Instruction Manual

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Appendix List (Application Notes)

Kaman P/N 860089-001 Rev. B

The Kaman KP Series Pressure Measuring system consists of sensor, cabling and signal conditioning electronics. The 1911 sensor is constructed as absolute (standard), gage, or differential and along with its attached cabling, it can operate at temperatures to 540° C (1000° F). The differential pressure sensor has a tube exiting from the sensor for a gaseous reference pressure. The gage pressure sensor has a filtered vent for atmospheric reference gas. The 2025 series is constructed as absolute only.

The single cable between sensor and electronics has two sections: the high temperature metallic sheathed cable plus a short, flexible section. The transition connector is limited to an operating temperature of 150° C.

The signal conditioning electronics is solid state consisting of an oscillator-demodulator that is used to excite the sensor and demodulate the return signal. Adjustment of "zero" and "gain" is provided. The sensing portion of the system should be considered as a discrete unit that consists of a sensor, the cabling and small circuit card within the electronics housing. These discrete sensing units are interchangeable with other oscillator-demodulators.

NOTICE

The diaphragm (end of sensor) is extremely fragile. Any non-uniform deflection may irreparably damage it!
The entire system must be properly installed prior to usage (including sensor, cabling, and signal conditioning electronics). In order that useful and safe measurements may be obtained, it is strongly recommended that this complete manual be studied prior to unpacking, installing, adjusting, or operating the system in any manner.

Unpacking:

Inspect the packing container for shipping damage. If damage is evidenced, notify the carrier prior to further unpacking and file the appropriate claim with the carrier. Notify Kaman Instrumentation Corporation, Customer Service Department if the contents are to be replaced or repaired.

Carefully unpack each item and identify it with shipping papers and packing lists. Prior to connecting the items or operating the system, study the next three sections of this manual, "Operating Principles", "Electrical Connections", and "Initial Checkout."

NOTE

The sensing element (diaphragm) is the end (flat) portion of the cylindrical sensor and it is fragile. It is protected during shipment with a cap which can also be used for subsequent protection when the sensor is not in use. Any non-uniform deflections (dents) may irreparably damage the diaphragm. It should not be touched or contacted with anything other than fluids or gases. (See Maintenance section for cleaning instructions).

Operating Principles:

The Kaman KP series of Measuring Systems utilize a principle of impedance variation. See figure 1. This variation is dependent upon the generation and decay of eddy currents within a conductive plate that is suspended on the diaphragm (end of sensor). This cyclic generation of eddy currents is caused when a coil that is "driven" by an oscillator is placed in close proximity to a conductive material; in this case, the diaphragm. The degree of coupling between the coil and conductive plate is dependent upon their common spacing and this coupling changes as this distance changes with varying pressures. The magnitude of eddy currents increases as this distance becomes less and energy is dissipated as these currents flow through the resistance of the plate. Thus, the "load", as represented by the coil's effective resistance and effective inductance (effective impedance), also changes which makes it a variable impedance transducer. Distances much less than 10^{-6} inches (2.54×10^{-5}mm) can be resolved in this manner.

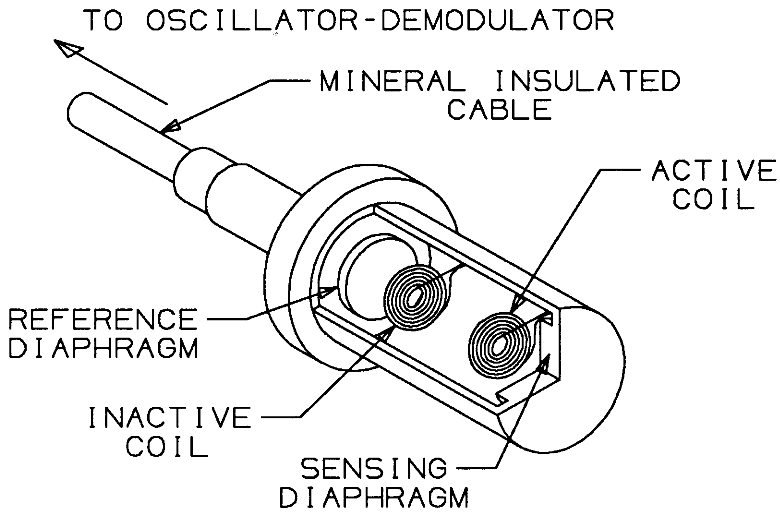


Figure 1

Two coils are used in an actual transducer; one experiences the impedance change due to pressure deflecting the diaphragm whereas the other is used for compensation of undesired environmental effects. Each coil is used as a component of an impedance bridge, the method of which was patented by Kaman. Since two coils are used, the transducers are very insensitive to radiation and temperature effects. Temperature causes changes of most physical properties of the materials used in the sensor and cabling but both halves of a symmetrical design respond to these changes in a similar manner.

A rapid temperature change, however will disallow complete compensation to be attained until both coils are at thermal equilibrium.

An oscillator is used to excite the coils through a driver amplifier. An error signal from the bridge is amplified and utilized by the demodulator for phase detection. The detected signal constitutes an analog output that is proportional to a change of pressure. The oscillator, demodulator, and part of the bridge circuit are housed in the electronics package. An external power supply (+ and -15Vdc) is required for operation of this electronics unit.

Electrical Connections:

(a) Sensor/Electronics Connections

The metal sheathed cable is connected to the flexible (soft) cable by means of a special indexed connector. This connector is designed to be rugged and small such that the pins are protected from normal handling damage. The sockets are recessed into a quick disconnect sleeve that is attached to the metal sheathed cable.

The standard transition connector should only be removed/installed by trained Kaman technicians. An optional removable connector is available and is shown in figure 2. To remove this connector, grasp the shell (1) and the backshell (2). Item (3) contacts unscrew then unplug from the cable. Note that pin #1 is active and must be reinstalled in the socket on the same side of the cable labeled "A".

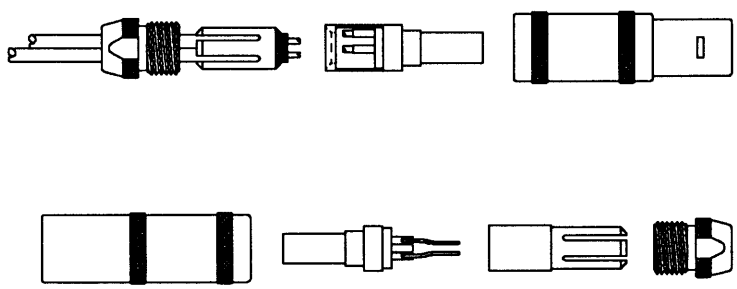


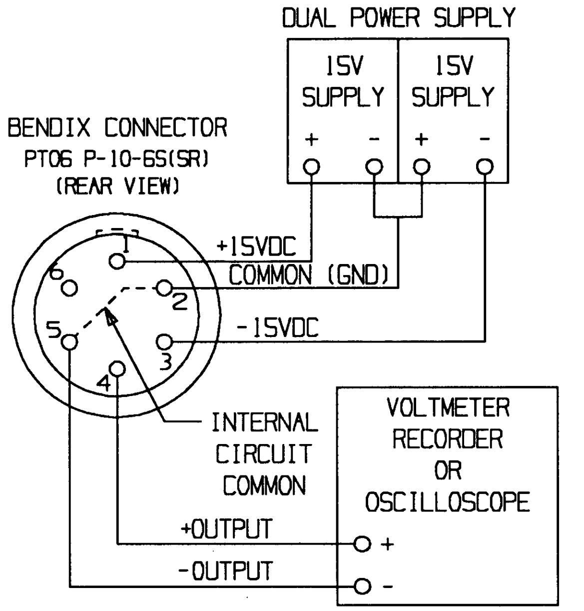
Figure 2

IMPORTANT: CAUTION!

Under no circumstances should the cable (either metal sheath or flexible) be shortened or extended. To do so will change the calibration of the system and will need to be returned to Kaman for recalibration.

(b) Power/Output Connections (Figure 3)

The input power requirements are + and -15Vdc (±0.5 Vdc) at 55mA. The Kaman Model P-3200 (for powering one to six units) or the Model P-3300 (including digital voltmeter with six channel selector switch) is recommended, although any 15 volt d.c. regulated dual supply can be used. The POWER/OUTPUT cable (part no. 853083-010) can be mated directly with the KP-1910 electronics package and the cable end leads are identified for connection to the power supply and readout instruments.



PIN	FUNCTION
1	+15Vdc (Positive supply input)
2	Ground (Supply input common)
3	-15Vdc (Negative supply input)
4	+ Output
5	-Output (Common with ground)
6	No connection

Figure 3

Output connections to a voltmeter, recorder, oscilloscope, or other readout device should be made as shown. Nominal output is 1 Vdc for full scale pressure (short circuit protected) from an output impedance of less than five ohms. Increased outputs are optional by special order.

The center connector on the electronics package is used for synchronization of electronics to prevent "cross-talk" between channels. This option is described in application note #205 of this manual. When this connector is not to be used, leave protective cap on this connector.

The maximum load capacity that can be used without signal distortion depends upon the full scale output voltage as represented in Figure 4. This may limit the output cable length when very long lengths are considered. For example, if the output voltage is 5 volts peak-to-peak, the maximum load capacity is 0.1 microfarad. If a cable with a capacity of 0.0002 microfarads per meter (200pf/m) is used,

the maximum length for a distortion-free output signal is $\dfrac{0.1\mu f}{0.0002\mu f\ /m} = 500 meters.$

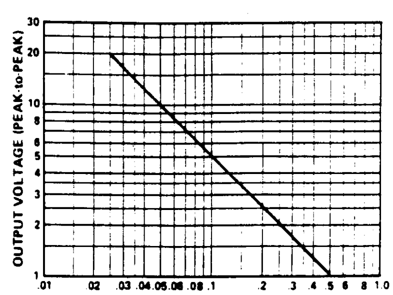


Figure 4

Initial Checkout:

The initial checkout is limited to checking the "zero" setting unless pressure can be applied to the sensor. If pressure and/or temperature are to be applied, the sensor should be mounted as described in the next sections and then the operation instructions should be followed for the checkout.

Assuming pressure is not available for this initial checkout, keep the protective cap over the sensor and connect the system as described in the previous section. (If several channels are to be synchronized, refer to application note #205 in this manual. Apply the + and - 15 volts d.c. power and allow approximately 1 hour for warm-up. The "zero" pressure output reading is different for an "absolute" sensor compared with "differential" and "gage" sensors. An "absolute" system should indicate the output voltage equivalent of zero pressure. A "differential" system should also indicate the output voltage equivalent of zero pressure provided the reference pressure tubing is open to the atmosphere. Refer to the calibration data for the pressure to output voltage conversion for each system. If readings other than those given above are indicated as the output, insert the small screwdriver (provided) into the "ZERO" opening of the electronics package where a small screwdriver slot is recessed within the case by approximately 1 centimeter. Rotate adjustment slightly to obtain the proper output. If the proper output cannot be attained, recheck all connections and again adjust the "ZERO". If the proper output is still not obtained, refer to the section on "Troubleshooting."

Sensor and Cabling Mounting:

The mounting of the sensor and cabling is vital to the system performance. Application note #203 in this manual gives a thorough description of the appropriate mounting considerations and should be studied prior to and followed during the mounting procedure.

Signal Conditioning Mounting:

The signal conditioning case has two flanges with two holes in each flange for mounting. These four holes are 0.201 inches (5.10 mm) diameter which makes them suitable for standard fasteners (no. 10, 0.190 inch dia.;M4.5, 4.5mm dia.; or M5, 5mm dia.).

Operation:

With the system properly mounted as described above, it is ready for operation. The power that is supplied to the power/output connector supplies power for the complete system. Allow a warm-up period of one hour to realize equilibrium temperature within the electronics for best stability of operation.

The media to which the diaphragm of the sensor is exposed should be free from directly impinging projectiles such as sand and dust. Severe thermal transients should also be avoided where possible since stability depends upon the time rate of change of the sensor temperature.

Calibration and test methods are described in Appendix C and these methods should be followed when testing the system operation.

Maintenance:

The sensor is a factory sealed unit and consequently routine maintenance is limited to care and cleaning. The appearance of the sensor is that of oxidized metal due to the operational temperature. Any foreign matter other than these oxides should be removed. The following steps should be used as a guide.

A. **NOTE:** The diaphragm, (end of sensor), is extremely fragile. Any non-uniform deflection may irreparably damage it. The diaphragm should never be touched or contacted with anything other than fluids or gases.

B. To clean the diaphragm, bathe it with a suitable solvent for the contamination and blow it with a mild air blast from the side, keeping the air source at least six inches from the diaphragm. Repeat as necessary.

C. The remainder of the sensor can be wiped with solvents and blown dry using the same techniques given in A and B. Protect the mounting flange sealing surface from scratches or flaws that may impair its sealing function. Use care to avoid getting solvents into gage or differential sensors. This could degrade the performance of the sensor.

D. Electrical connectors are subject to contamination under repeated use. These should be inspected for foreign matter on the contacts and should be cleaned with an electronic contact cleaner as required. The connectors on the soft cabling should be checked for fit to the cabling since organic materials creep and they may tend to become loose. They should be tightened or rebuilt if necessary. Alteration of lengths of this cabling for connector repair will alter calibration. The calibration should be checked if such a repair is required. A factory compensation may be required if the calibration cannot be retained.

E. Maintenance of the signal conditioning electronics is limited to cleaning alone. The connector contacts should be cleaned with electronic contact cleaner periodically, especially if disconnected repeatedly.

Troubleshooting:

This section provides a guide for isolating the cause of malfunctioning of the pressure measuring system. The sensor can be checked for coil integrity as follows:

A. Disconnect the connector between the solid sheathed cable and the soft cabling.

B. Using an ohmmeter that does not have a battery voltage greater than 3.0 volts, check continuity from each pin of the connector to the sheath. The values should be:
Sensors with less than 20 feet solid sheath cables: both active and inactive cables should indicate approximately 10 to 15 ohms at room temperature. The resistance values from the pin-to-pin should be twice the value from pin-to-sheath.
Values grossly larger or smaller than these values indicate a faulty sensor assembly.

C. Check all connectors for cleanliness and make certain that contact is being made. Clean if necessary.

D. Contact Kaman Instrumentation Corporation Customer Service Department if other difficulties are experienced.

Appendix A

MODEL NUMBER INDEX KEY

Each transducer is serialized and identified with a model number according to the index given below. The model number gives extensive information about the measuring system.

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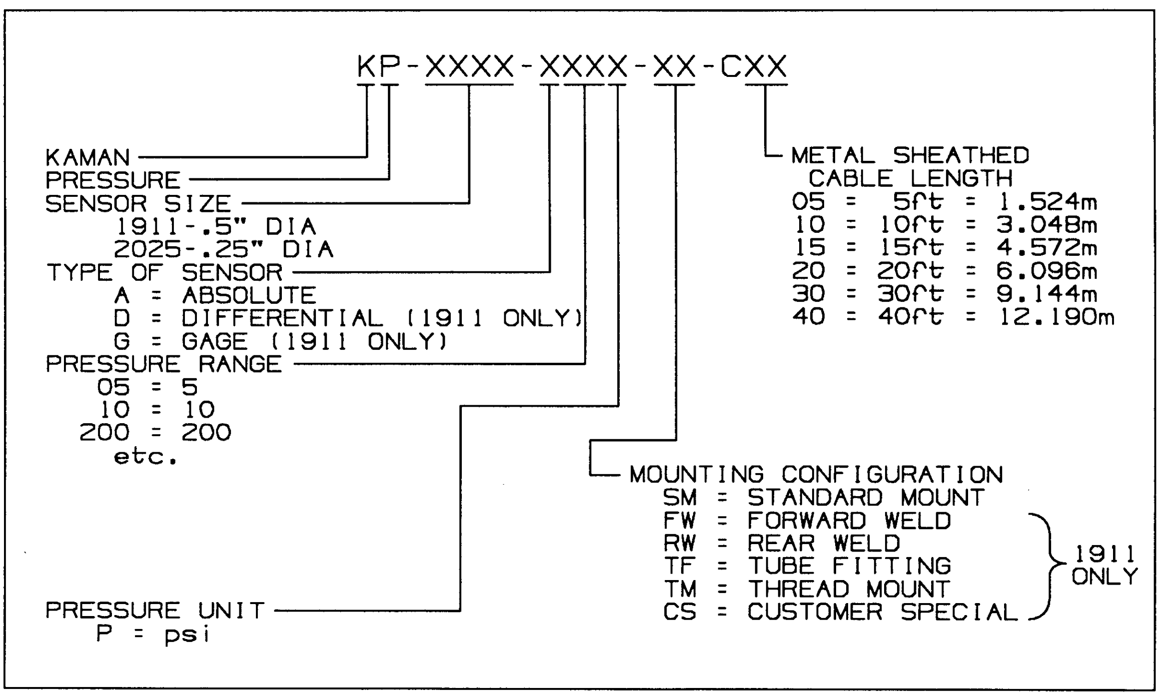

Appendix B

PRESSURE CONVERSION FACTORS

The following pressure conversion factors are given for convenience in converting between units of pressure measurement:

PRESSURE CONVERSION FACTORS

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	(A) atm	(D) dyne/cm^2	(I) in. of water	(C) cm of Hg	(K) kgf/m^2	(N) N/m^2	(P) psi	(F) lb/ft^2	(B) bars
1 atmosphere =	1	1.013×10^{6}	406.8	76.00	1.033×10^{4}	1.013×10^{5}	14.70	2116	1.013
1 dyne/cm^2 =	9.869×10^{-7}	1	4.015×10^{-4}	7.501×10^{-5}	1.020×10^{-2}	0.1	1.450×10^{-5}	2.089×10^{-3}	10^{-6}
1 inch of water at 4° C =	2.458×10^{-3}	2491	1	0.1868	25.40	249.1	3.613×10^{-2}	5.202	2.491×10^{-3}
1 cm of mercury at 0° C =	1.316×10^{-2}	1.333×10^{4}	5.353	1	135.9	1333	0.1934	27.86	1.333×10^{-2}
1 kilogram-force per m^2 =	9.678×10^{-5}	98.07	3.937×10^{-2}	7.356×10^{-3}	1	9.807	1.422×10^{-3}	0.2048	9.804×10^{-5}
1 newton per m^2 (1 pascal) =	9.869×10^{-6}	10	4.015×10^{-3}	7.501×10^{-3}	0.1020	1	1.450×10^{-4}	2.089×10^{-2}	10^{-5}
1 lb per in.^{2} =	6.803×10^{-2}	6.895×10^{4}	27.68	5.171	7.031×10^{2}	6.895×10^{3}	1	144	6.897×10^{-2}
1 lb per ft^2 =	4.725×10^{-4}	478.8	0.1922	3.591×10^{-2}	4.882	47.88	6.944×10^{-3}	1	4.787×10^{-2}
1 bar =	0.9869	10^{6}	401.5	75.01	1.020×10^{4}	10^{5}	14.50	2.089×10^{3}	1

EXAMPLE: 1 Atmosphere = 1.013×10^{6} Dynes/cm^2

Appendix C

CALIBRATION and TEST METHODS

The KP series pressure measuring systems offer two calibration options:

1. The standard system includes a room temperature calibration. Compensation for thermal shifts is built into the system.
2. Optional calibration at high temperatures can be obtained in which case a computer analysis, printout, and graph of the data are provided. Compensation for thermal shifts is built into the system. In the event that the calibration is checked or performed by the user, the following steps can be used as a guide.

CALIBRATION PROCEDURES

The system compensation is accomplished prior to the system's leaving the manufacturer. During this process the selected components are installed for matching the electronics, cabling and sensor. These values are selected to provide the minimum values of thermal shifts of both zero and sensitivity. The systems are so compensated and calibrated with the connections as described in the basic manual. It is vital to the system operation that the system be connected as shown with matching serial numbers and consistent cable connections. The cables cannot be shortened or additional lengths added or omitted without altering the calibration that has been set at the factory.

Details for checking and making fine adjustments to the calibration are described as follows.

1. The sensor should be installed in a pressure fixture as described in the Mounting Application Note #203 in this manual. This fixture should then be put in an appropriate heat source such as an oven or furnace that can be temperature controlled.
2. Power is applied and a period of 1 hour for stabilization should be allowed. The output can be read by a suitable recorder or voltmeter.
3. With zero pressure applied to the sensor, adjust the "ZERO" for zero output voltage.
4. Apply full scale pressure and maintain while adjusting the "GAIN" control for the specified output.
5. Check the zero and repeat steps 3 and 4 if necessary.
6. The gain and zero can be set at any desired sensor temperature to obtain the best characteristics for the operating conditions.
7. Additional calibration can be made by following the procedures given for specific characteristics as outlined in Test Procedures.

TEST PROCEDURES

For testing the systems, they should be connected as described in the basic manual. In addition, it may be desirable to use a low temperature pressure transducer of very accurate characteristics as a reference system. This transducer should be connected to the same pressure source as the KP series sensor and output of this reference transducer can be used to drive the x-axis of an x-y recorder. Any errors of the reference system will be represented as errors on the pressure axis (x-axis) of a pressure-output chart of the KP system. This is the reason for the accurate reference system requirement. The gain of the reference system can be adjusted to normalize the axis into the desired pressure units.

The y-axis of the recorder is then driven by the output of the KP series system. A digital voltmeter can be used as a parallel readout to provide accurate readings. With this system, the high temperature sensor can be subjected to its full thermal and pressure environmental ranges and a family of curves can be used to measure linearity, hysteresis, thermal zero shift, sensitivity, thermal sensitivity shift, and total error band of the system. If more accuracy is desired, the digital readout can be used.

Specific tests can be performed as follows to provide quantitative data for the listed characteristics. These tests can be performed at any temperature of the sensor.

A. <u>Overpressure</u>

1. Record the system output at zero pressure (re-zero if desired).
2. Increase (or decrease) pressure to the KP series sensor to the overpressure value specified for the particular pressure range.
3. Return pressure to zero and record output.
4. Calculate zero shift for either or both directions as a per cent of full scale.

B. <u>Linearity</u>

1. Record output with pressure in desired increments (or continuously) to full scale pressure.
2. Determine the ideal straight line. This line can be forced through end points, through zero, or a best fit line.
3. Calculate the deviation from ideal at each recorded increment as a percentage of full scale. This deviation represents the non-linearity of the system.

C. <u>Hysteresis</u>

1. Record output with applied pressure in desired increments for both increasing and decreasing pressure.
2. Determine any differences in output at a given pressure for increasing and decreasing pressure.
3. Relate these differences to a percentage of full scale output to determine hysteresis.

D. <u>Sensitivity</u>

The sensitivity has been set by the manufacturer to provide the required output range for full scale pressure. The "GAIN" adjust can be used to change this sensitivity. The sensitivity (slope of output-pressure curve) can be monitored at several sensor temperatures. Any deviations can be expressed as a thermal sensitivity shift in percent per degree of temperature change.

E. <u>Zero</u>

The system output for zero pressure can be monitored as temperature of the sensor is varied. The deviations can be expressed as a thermal zero shift in percent of full scale per degree of temperature change.

F. <u>Electronics Tests</u>

Steps A through E above are normally performed with the electronics at constant temperature. The same tests can be performed with the sensor at constant temperature and the electronics at varied temperatures. These tests will indicate the advisability of maintaining the signal conditioner at constant temperature for best system stability.

G. <u>Shock, Acceleration, and Vibration Testing</u>

1. The signal conditioning electronics, cabling and sensor should all be mounted as recommended in this manual.
2. The tests can then be performed per standard testing methods.

H. <u>Other Tests</u>

The other environmental and performance tests can be accomplished without further elaboration. The normal precautions concerning the diaphragms and the reference gas being free from moisture and contaminants must be observed. In no event should any conditions that are specified for the system be exceeded.

APPLICATION NOTE #203

Mounting considerations for the KP-1911 series high temperature pressure transducer

I. Introduction

The purpose of this application note is to provide mounting information for the users of the KP Series high temperature pressure transducers. Proper attention to the mounting details of the cable and transducer will lead to long-term performance and high integrity measurements.

Included in this note are the mounting details for the high temperature cable and the mounting of the transducing sensor.

In the discussion of these mounting options, several vendor products as well as welding or brazing mounting designs are discussed. Since Kaman cannot in any way control vendor performance in the supply of standard products or customer materials or welding and brazing procedures, Kaman cannot assume any responsibility or liability beyond the actual hardware furnished to the customer. However, Kaman personnel have extensive backgrounds with the mounting of transducer systems and would be pleased to discuss the mounting problems.

II. General Considerations

In general, the KP Series Pressure Transducer is a rugged instrument suitable for most measurement situations, but a few precautions must be observed during mounting to assure satisfactory life and performance of the transducer. These are:

Electrical Connections: Care must be exercised to avoid contamination or damage to the contacts. Whenever possible, a cover (such as shrink sleeve) should be used for protection.

Metallic Sheathed Cable: The cable sheath is made of .012 inch (.305mm) wall thickness tubing. This thin wall aids in making the cable flexible, but makes other precautions advisable. Care should be exercised to avoid scraping and gouging of the sheath. Unnecessary torque or bending should not be applied to the cable since the resulting work-hardening will greatly reduce the flexibility of the cable. Repeated flexing and/or very tight bends, especially at the sensor can cause failure of the cable.

Transducer Mounting Flange: The mounting flange is provided with close tolerances and a fine surface finish. These features are of great importance for the successful use of the flange in conjunction with metallic seals discussed later. If the transducer is sealed into the bulkhead using metallic seals, protective measures should be employed to avoid nicks, scratches or dents of the sealing surfaces.

Reference Pressure Tube and Porous Plug: Sensors to be used either as differential or gage transducers are provided with a reference pressure tube or porous plug respectively. With such transducers, special care should be used to prevent the entry of foreign matter into the sensor. A cap over the end of the reference pressure tube or a piece of tape over the porous plug should be used as a barrier against dust, moisture, or solvents. Such entry could seriously degrade transducer performance.

Sensor Diaphragm: The diaphragm (sensor end) is an extremely important element in the proper functioning of the transducer system. As a flexible deflection member, any change in the diaphragm characteristics will seriously affect the transducer system performance. During all mounting operations, great care should be exercised to avoid any contact on the diaphragm surface except with cleaning solvents. **At no time** should mechanical or chemical cleaning processes be used to clean the diaphragm. The oxidized metal look is normal after exposure to elevated temperatures. The protective cover supplied should be used whenever possible.

To clean the diaphragm, bathe it in a suitable solvent for the contamination and blow on it with a mild air blast from the side, keeping the air source at least six inches (150mm) from the diaphragm. Repeat this procedure as necessary. The remainder of the sensor can similarly be cleaned with special consideration being noted for differential or gage transducers and their respective reference pressure tube or porous plug.

III. Metallic Sheathed Cable Mounting

Mounting problems associated with the high temperature metallic sheathed cable include considerations for the routing and attachment of the sheath and the possible penetration of the cable through a bulkhead or similar structure. Since the cabling is a vital part of the transducer system, the design aspects of the cable mounting should be considered carefully.

A. Routing Problems

The metallic sheathed cable will withstand continuous service at a temperature of 1200° F (650°C) with exception of the special two pin connector. This connector is limited by the service life of the inorganic material, but can survive continuous use at 300°F (150°C). Furthermore, system performance can also be aided if the amount of heated cable assembly is kept to a minimum. Since the amount of heated cable and the thermal environment is generally unknown until installation, these thermal errors are unaccounted for by the calibration. The decrease of the system sensitivity by the thermal environment is approximately 1% per ohm of cable resistance change. With the special design of the KP-1911 metallic sheathed cable and consideration of the cable routing, this decrease is usually negligible.

Other routing problems concern the bending and flexing of the cable sheath. The cable is designed to withstand a 0.25 inch (6.35mm) minimum bend radius provided a mandril is used. Such small radius bends are not recommended close to the sensor portion of the cable since such bends would excessively strain the cable-to-sensor weldment. Repeated bending of the cable work hardens the sheath and increases the risk of failure during subsequent bending. Because of this, it is strongly recommended that the cables be bent a minimum number of times (preferably once) and that a mandril be used for bends of 1 inch (25.4mm) radius or less.

B. Cable Clamping

In operation, there are several important considerations relating to the clamping of the cable. First the cable must be fastened to avoid unnecessary strain and vibration fatigue. Since the resonant frequency of an unsupported cable is related to the cable diameter divided by the square of the unsupported length, cable clamps should be used with as close a spacing as practical. Also, since the cable clamp creates a point of maximum stress, a resilient liner such as silicon rubber or Teflon to temperatures of 550°F (288°C) or woven metal at higher temperatures is suggested to reduce the high stresses. In all cases, the cable clamp selected should not excessively swage the cable or have any sharp edges which would cut or damage the cable sheath.

Secondly, the cable should be mounted such that circuits of different potential are not shorted through the cable sheath. Since the sheath of the transducer is at ground potential (and this is vital to the operation of the transducer) care must be taken to avoid this situation. This is especially true with high frequency circuitry since a slight modulation of the output can result.

Finally, slight zero shifts (a fraction of a percent) can be caused by changes of the total sheath resistance as sensed by the system electronics. This shift can be compensated by adjusting the "zero" control at the electronics but should be avoided if possible. Such shifts are caused by shorting of the sheath to itself in excess or expansion cable coils, or by the use of conductive cable clamps which would shunt the cable resistance through a lower resistance mounting surface. With these factors in mind, it is suggested that the cable be isolated from ground between the sensor and electronics using insulated cable clamps.

C. Bulkhead Feed-through (KP-1911 only)

Each high temperature cable is fitted with two sleeves (see B in figure 5). These sleeves are provided for identification or for use with swage fittings (see C in figure 5) required for penetrations of pressure bulkheads. The sleeves and the metallic sheathed cable connector are designed to pass through the swage fittings for ease of cable routing and mounting. Each sleeve measures 1.50 inches (38.xmm) long by 0.187 inches (4.75mm) in diameter and is usually fabricated using Inconel Alloy 600 material. If swage fittings are used, they must not be tightened to the manufacturer's recommended number of turns (usually 1-1/4 to 1-1/2 turns) but they should only be tightened enough to clamp the cable sheath without appreciable denting. If the precise locations of bulkheads are known, the sleeves can be attached to the cable sheath with a leak tight weld (<1x10-8 std cc He/sec) to assure even greater sealing capability. Field welding of the sleeves to the cable sheath is not recommended and brazing procedures should not require temperatures above 1700°F (927°C) since chemical reactivity and material grain growth are excessive at higher temperatures. Kaman personnel can be contacted for advice and assistance concerning these problems. Kaman can weld the sleeves in place on special order. A partial list of vendors of swage fittings which can be used successfully with the cable sleeves are:

Vendor	Part No. Designation
Swagelok	300-1-2-BT-316
Conax	MK-187-A-Stainless Steel
Parker Hannifan	3-2FH4BZ-SS

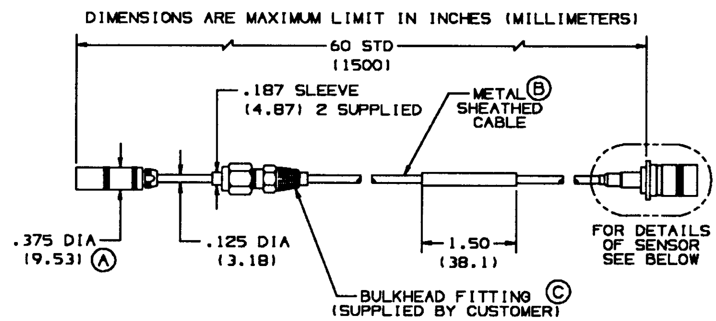


Figure 5

IV. Mounting of the Reference Pressure Tube

Each differential pressure transducer is supplied with a 1/16 inch (1.59mm) diameter by 0.012 inch (.305mm) wall thickness Inconel Alloy 600 reference pressure tube (see Figure 6.) Routing and mounting of this tube should follow the same guidelines presented for the metallic sheath instrumentation cable except that there would usually be no necessity for electrical isolation.

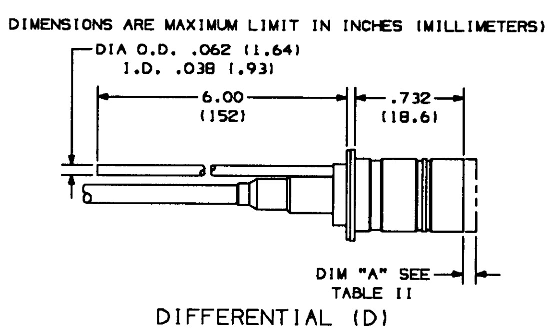


Figure 6

The use of fittings or welding is suggested for the attachment of the reference pressure tube to other pressure lines. If brazing techniques are employed, a braze material with a melting temperature greater than the anticipated service temperature but less than 1700°F (927°C) should be used. **Sparing amounts of braze flux should be used** since any amounts of flux that might permeate into the interior of the sensor could destroy the transducer. A torch with a very small tip should be used to avoid excessive heating of the cable or sensor. These same precautions also apply to any welding procedure.

V. Sensor Mounting (KP-1911)

Because of the diversity of customer applications, several configurations for the mounting of the sensor are offered. Each configuration has its advantages and disadvantages that need to be considered before the final selection of the desired mounting. The major considerations of each configuration are presented in Table I. Also, special sensor mounting designs can also be considered. Kaman personnel will be pleased to examine and furnish a quotation for the exact requirement upon request.

DESIGN	CODE	MOUNTING TYPE	ADDITIONAL WELDING REQUIRED	DEGRADATION OF SYSTEM FREQUENCY RESPONSE	OTHER CONSIDERATIONS
STANDARD MOUNTING	SM	REMOVABLE	NO	SLIGHT	REQUIRES PREPARATION OF PRECISION GLAND
TUBE FITTING MOUNTING	TF	REMOVABLE	NO	EXCESSIVE	
THREADED MOUNTING	TM	REMOVABLE OR FIXED	NO OR YES	MODERATE	REDUNDANT MOUNTING OFFERS HIGH RELIABILITY. CABLES MUST BE ROTATED DURING INSTALLATION.
FOWARD WELD MOUNTING	FW	FIXED	YES	MODERATE	HEAT SINK SUGGESTED TO PROTECT SENSOR FROM WELDING HEAT
REAR WELD MOUNTING	RW	FIXED	YES	SLIGHT	HEAT SINK SUGGESTED TO PROTECT SENSOR FROM WELDING HEAT

TABLE I
SENSOR MOUNTING DESIGN COMPARISON

Of the configurations offered, only two, the Standard Mounting (SM) and Tube Fitting Mounting (TF), are designed to be totally removable. The third, the Threaded Mounting (TM), can be removable provided there is no leakage requiring the welding of the mount in place (this would only be possible with fluids of high viscosity). The other two configurations, the Forward Weld Mounting (FW) and Rear Weld Mounting (RW), require in-place welding and when properly welded, create a hermetic seal to the mounting bulkhead.

All fixtures for the mounting configurations are fabricated from Inconel Alloy 625 which is described as being "readily weldable" by either tungsten electrode or consumable electrode of Inconel Filler Metal 625. Before any welding is performed, Kaman suggests that test specimens be fabricated and that all weld procedures be practiced before the actual welding of the sensor adapter. In all cases, the transducer sensor (especially the diaphragm) and cabling must be protected from the heat and molten slag of the welding process. Since the transducer system is sensitive to movements of less than a millionth of an inch (2.54 x 10-5mm), only welding procedures using the mounting adapters are allowable. Welding to the sensor case or mounting flange after assembly and calibration would have the risk of invalidating the calibration or destroying the sensor completely. Kaman personnel are available for consultation concerning welding problems but for questions about the weldability of Inconel Alloy 625 to a specific alloy, contact the Technical Services Department of Huntington Alloys, Huntington, West Virginia.

The frequency response requirements of the transducer system should also be considered when choosing the sensor mounting. In general, a recessed or tube mounted sensor will have degraded frequency response because of the restricted flow conditions; whereas, a forward mounted sensor (where the diaphragm is near the inner edge or protrudes into the vessel cavity) will have a useful frequency response limited only by the natural frequency of the sensor diaphragm as indicated in Table II provided the electronics has sufficient output bandwidth.

TABLE II:
PRESSURE RANGE VS.
DIMENSION "A" AND
FREQUENCY RESPONSE

STANDARD FULL SCALE PRESSURE RANGE psi	DIAPHRAGM THICKNESS (DIMENSION "A") KP-1911		AVERAGE FREQUENCY RESPONSE 25°C TO 540°C (ZERO TO INDICATED FREQUENCY WITHIN 3db)
	INCHES	MILLIMETERS	
5	.003	.076	1460
10	.004	.102	2100
20	.005	.127	2870
50	.007	.178	4350
100	.009	.229	5860
200	.011	.279	8330
500	.015	.381	12270
1000	.019	.483	16280
2000	.026	.660	26200
3000	.032	.813	34900
5000	.042	1.067	45990

TABLE III:
PRESSURE RANGE VS.
DIMENSION "A" AND
FREQUENCY RESPONSE

STANDARD FULL SCALE PRESSURE RANGE psi	DIAPHRAGM THICKNESS (DIMENSION "A") KP-2025		AVERAGE FREQUENCY RESPONSE 25°C TO 540°C (ZERO TO INDICATED FREQUENCY WITHIN 3db)
	INCHES	MILLIMETERS	
50	.003	.076	1,400*
100	.0038	.097	1,750
500	.0065	.165	3,100
1000	.0082	.208	3,800
3000	.012	.305	5,600

* CROSS-AXIS RESONANT PEAK @ 1,500 Hz

Other considerations affecting the choice of the sensor mounting design would be such factors as access for machining and precision welding and cable routing where the rotation of cables during thread engagement is necessary. The specific details of each of the mounting designs are presented in the following discussion.

A. Standard Mounting (SM)

The standard mounting (SM) is a removable, high frequency response mounting which requires some machining and the purchase of a high temperature metallic seal. The sensor flange is a flat, polished surface (16x10-6 inches(406x10-6mm)root-mean-square surface finish with no radial tool marks) suitable for use with metallic seals to temperatures of 1000°F (538°C) and pressures of 5000 psi. Mounting dimensions of the sensor are shown in figure 7.

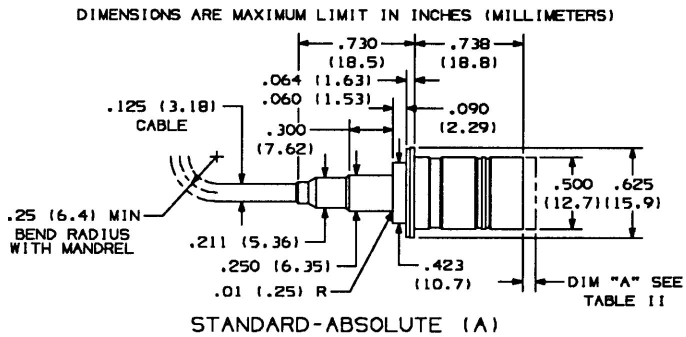


Figure 7

The seal gland must be fabricated to accept the sensor and the metallic seal in such a manner that a controlled compression of the metallic seal occurs (see figure 8). Since the metallic seal is in fact a high temperature spring, over-compression could damage or destroy the metallic seal limiting its sealing capability and reusability. Actual gland dimensions for use with the various metallic seals are listed in Table III. The surface finish required on the sealing surface (marked (A) in figure 8) depends on the pressure media, pressure and temperature. In general, an 8 to 10 (203 to 254) rms finish is required to seal against helium, 16(406)rms for most cases and thin liquids, and a 32(813) rms finish for most liquids. The surface must be free of any radial, spiral or transverse tool marks as such marks would be potential leak paths. Flatness of the sealing surface should be within .0005 inches per inch (.0005mm per mm) of circumference and parallelism of the gland should be within 0.0015 inches (.038mm) total indicated reading of the clamping surface.

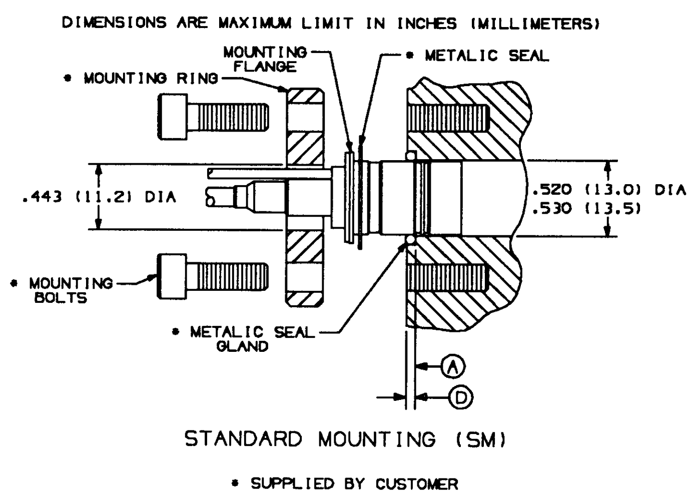


Figure 8

Factors to consider in the selection of the metallic seal would be the service temperature and pressure, and the chemical compatibility of the seal materials with pressure media. Since specific details such as temperatures, pressures, exposure times, concentrations and impurities may vary from application to application, it is suggested that the seal manufacturer be contacted before the purchase of specific metallic seals. For general reference, the following list indicates the possible application of metallic seal materials and coating:

Environment	Suggested Seal Material and Coating
High Humidity	Nickel alloy with silver
Salt Spray	Nickel alloy with silver
Water	Nickel alloy with silver
Combustion Gases	Nickel alloy with gold
Helium	Nickel alloy with gold
Most Acids	Stainless steel with gold
Liquids & Gases	Stainless steel with Teflon
Liquid Metals	Nickel alloy with nickel

The coating material serves the function of blocking all the leak paths between the two mating surfaces. Since no two surfaces are perfect, the coating material provides a thin deformable solid surface which fills the micro-asperites of the mating surface creating the seal. In general, the coating material which has the highest deformability and still is compatible with system environment will provide the best performance and service life with the maximum reusability.

A partial list of manufacturers and pertinent data for the use of metallic seals that could be used with the KP-1911 sensor are listed in Table IV. The data presented has either been obtained from their literature or by correspondence. Those noted with an asterisk have been used at Kaman in calibration and testing procedures.

When mounting the sensor and metallic seal to the bulkhead, engineering judgment should be used to select the materials and number of bolts to withstand the service times, temperature, and pressures. Bolts holding the mounting ring should be tightened evenly such that uniform compression of sensor flange and metallic seal result. A bolt tightening sequence of opposite bolts using a torque wrench is recommended to accomplish this; that is, 1-3-2-4 for a four bolt pattern and similarly for any greater number of bolts. Care must also be used to avoid over-tightening and pre-stressing of the bolts leading to premature failure. If severe vibration will be encountered, the use of lock washers and/or safety wires is recommended.

The sealing surfaces of the ring, sensor and mount must be thoroughly cleaned with a solvent prior to assembly. If the flange of the sensor or mount has been scratched or damaged, they should be polished prior to assembly. A tube with an inside diameter of 33/64 inch (13.09mm) can be used to polish the sensor flange. The end of the tube must be square with this inside diameter. The tube should have a chamfer to avoid the radius at the base of the flange of the sensor. Using double sided tape, stick a "washer" of #600 or finer emery paper to the end of the tube. The inside diameter of the washer should be 33/64 inch (13.09mm). Insert this tube over the diaphragm and rotate the tube such that the emery paper polishes the flange in a circular motion only. A similar tool, (or the same tool if it has the proper outside diameter) , can be used to polish the seat of the mount. When solvents are used on the sensor for cleaning, caution must be taken to prevent entry into either the reference pressure tube or the porous plug of either the differential or gage sensors.

The reusability of the metallic seals is dependent on the maintenance of the surface finishes, cleanliness and the careful handling of the metallic seal and sensor flange. With some uncertainty, several uses could be expected from a given metallic seal with the sealing surfaces being repolished as described previously between usage.

uncertainty, several uses could be expected from a given metallic seal with the sealing surfaces being repolished as described previously between usage.

Vendor	Basic Part Number Basic material	Coating Dash No.	Coating	Max. Service Temperature	Est. Press. capability at 1000°F (538° C) or max. service temperature	Seal Gland Diameter	Seal Gland Depth [a] (See "D" in figure 8)
Hydrodyne Div. of F.P.I., INc. 7041-1/2 Vineland Ave., North Hollywood, CA 91605	11-4845 Base Material Inconel Alloy 718	-1* -2 -3 -4 -5	Silver Nickel Unplated Gold Teflon	1400°F(760°C) 1400°F(760°C) 1400°F(760°C) 1400°F(760°C) 480°F(249°C)	5000 psi 5000 psi 5000 psi 5000 psi 5000 psi	.633±.002 inches dia. (16.078± .051mm dia.)	.106±.001 inches (2.692± .025mm)
Parker Seal Co. 10567 Jefferson Blvd. Culver City, CA 90230	8910-21XX-0062 Base Material Inconel Alloy 718	XX=01* XX=02 XX=03	Silver Gold Teflon	1400°F(760°C) 1400°F(760°C) 500°F(260°C)	5000 psi "b" 5000 psi "b" 5000 psi "b"	.627+.005/-.000 inches dia. (15.926 +.127/ -.000mm dia.)	.107±.001 inches (2.718± .025mm)
Haskel Engineering and Supply Co., 100 East Graham Place, Burbank, CA 91502	HVX2-10 Base Material 17-4PH Stainless Steel	X=S X=G	Silver Gold	800°F(427°C) 800°F(427°C)	6000 psi 6000 psi	.633±.002 inches dia. (16.078± .051mm dia.)	.108±.001 inches (2.743± .025mm)

* Seals have been successfully used by Kaman and Kaman customers.

a Based on nominal sensor flange thickness of 0.063 inches. Actual varies from .062 to .064 inches and appropriate adjustments should be made for the actual flange thickness.

b Manufacturer states that the use of thicker plating can increase this pressure range.

Table IV

B. Tube Fitting Mounting (TF)

The tube fitting mounting (TF) is a low frequency response mounting designed for use with 37 degree (41.11 grad) flared tubing. The mounting (shown in Figure 9) is designed to withstand the maximum specified service temperatures and pressures of the transducer sensor. The mounting is fabricated from Inconel Alloy 625 which is compatible with most industrial and chemical environments. Since mounting to a tube implies a somewhat remote location from the pressure source, this mounting design should only be considered for low frequency or static pressure measurements. Use of this mounting with a stand-pipe or similar structure allows the sensor to be used effectively for the following:

Pressure measuring of an extremely high temperature pressure source (greater than 1000°F {538°C}) while placing the sensor in a temperature zone within its operating range.

Pressure measurements in process or fluid transfer piping systems where direct insertion of the sensor into the piping would impede flow.

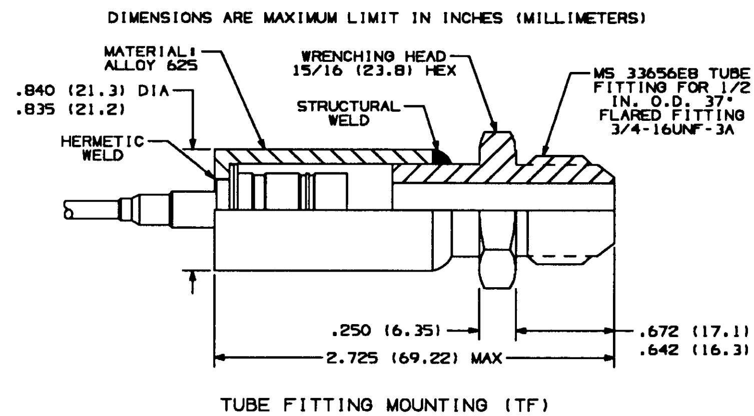


Figure 9

Mounting considerations for this design should include careful preparation of the mating surfaces to the 37 degree (41.11 grad) conical surface. A mating surface finish of 32(813) rms or better with no nicks or burrs is recommended. If gas-tight seals are required, the application of a soft plating material compatibile with the media and environment could be considered. Coating materials such as silver, gold, and teflon as described in the Standard Mounting section could be used. A hexagonal wrenching surface is provided for tightening of the mounting. A pipe wrench or slip joint pliers should not be used on the cylindrical surface of the mounting since jaw marks could cause stress concentrations that could lead to eventual failure. During the wrenching procedure, if it is necessary to rotate the sensor, care should be taken to avoid unnecessary torsion on the metallic sheathed cable assembly.

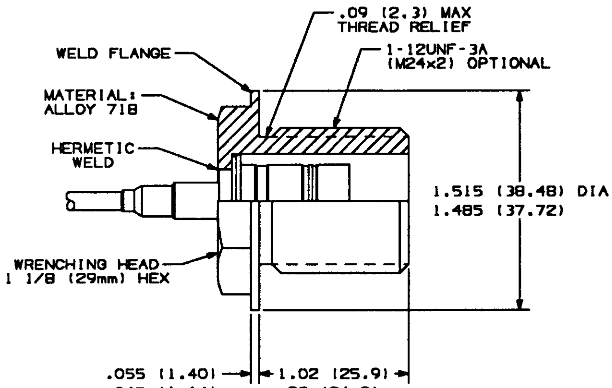
C. <u>Threaded Mounting (TM)</u>

The threaded mounting (TM) design can be used as a removable mounting or welded in place to provide a hermetic seal and a redundant mount attachment. The mounting is fabricated from Inconel Alloy 625 and is designed to withstand maximum specified service conditions of 1000°F (538°C) and 5000 psi. Two thread designs are available to customers. The mating bulkhead surface of the surface marked (A) in Figure 10 should be a flat surface (within 0.002 inches {0.51mm}). This is necessary to avoid excessive gaps which would make welding difficult. If welding procedures are used, the sensor and metallic sheathed cable must be protected from the heat and slag of the welding process. Weld test specimens are suggested prior to making the final in-place weldment.

The use of this mounting as a removable mounting should only be considered if leakage is no problem or it is intended for use with highly viscous fluids. Furthermore, surface (A) is not intended for use with metallic seals since the mounting must be rotated and such action against a metallic seal would destroy its sealing capability. Since the mounting must be rotated during the thread engagement, extreme caution must be exercised to prevent any unnecessary torque from being applied to the metallic sheathed cable.

The effect of this mounting on the system frequency response is small if the distance to the pressure cavity is no greater than the distance from the diaphragm to the forward edge of the mounting adapter.

DIMENSIONS ARE MAXIMUM LIMIT IN INCHES (MILLIMETERS)



THREADED MOUNTING (TM)

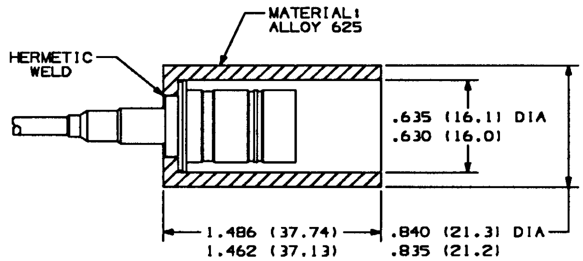
Figure 10

D. Forward Weld Mounting (FW)

The forward weld mounting (FW) is a fixed mounting requiring in-place welding. The adapter, like all others, is fabricated from Inconel Alloy 625 and shown in Figure 11. During welding procedures, extreme caution should be exercised to protect the sensor and the metallic sheathed cable from the heat or slag of the welding process. Heat sinks which could be located on the weld adapter to protect the sensor from excessive thermal environments are suggested. Weld test specimens are also suggested before the actual in-place weldment is made.

The effect of this mounting on the system frequency response is also small if the distance to the pressure cavity is no greater than the distance from the diaphragm to the forward edge of the mounting adapter. This adapter, like all others, is designed for use at the maximum temperature and pressure of 1000°F (538°C) and 5000 psi.

DIMENSIONS ARE MAXIMUM LIMIT IN INCHES (MILLIMETERS)



FOWARD WELD MOUNTING (FW)

Figure 11

E. Rear Weld Mounting (RW)

The rear weld mounting (RW) (see figure 12) is similar in most respects to the Forward Weld Mounting (FW). The major difference is that the sensor can be placed directly into the pressure cavity for the best system frequency response. Since with this mounting, the sensor diaphragm is unprotected by the adapter, care must be exercised so that it is not bumped, scraped, or dented. Other considerations prior to welding would be the protection of the sensor and the cable from the heat or slag of the welding process and the use of heat sinks as mentioned with the Forward Weld Mounting. Weld test specimens are also suggested before the actual in-place weldment is made.

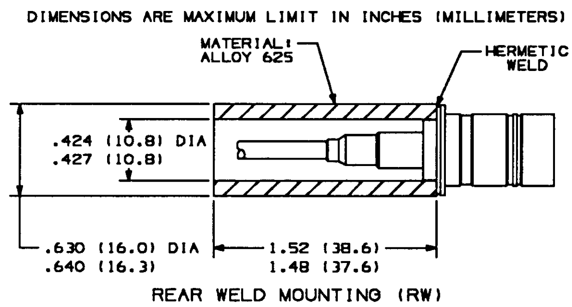


Figure 12

VII. Sensor Mounting (KP-2025)

The KP-2025 is available in Standard Mount (flanged) configuration only. It is designed to be mounted as shown in figure 13. The "O" ring shown is available from Kaman (P/N 825335-005) or from its manufacturers: American Seal & Engineering Co. Inc. P/N MS9371-07. Because the "O" ring is silver plated, a surface finish of 16rms is sufficient as long as there are no radial scratches in the sealing surfaces.

Figure 14 shows the detailed dimensions of the bolted mounting ring. The 0.135 wide slot is not required if the removable Lemo option was selected. All the precautions described in section IV, a. Standard Mount for the KP-1911 should be observed.

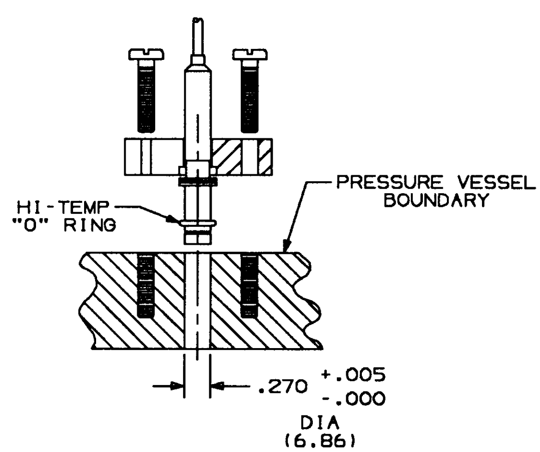


Figure 13

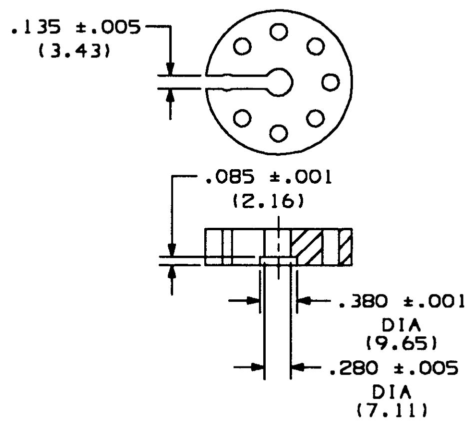


Figure 14

APPLICATION NOTE #205

Synchronization of KP Series Pressure Measuring Systems

Introduction:

When two or more KP Series systems are used together, there is the possibility that interference (or "cross talk") may be generated. This interference is in the form of "beat" frequencies detectable on the system outputs. Such "beat" frequencies correspond to the differences between the drive frequencies of the oscillators of the multiple systems and these differences can be several Hertz. These interferences can be eliminated by synchronization of all oscillators to a single oscillator, called "master" oscillator. The "slave" oscillator frequencies are then identical to that of the master oscillator.

Three basic methods exist whereby interference (or cross talk) can be introduced. The most common source is ground loops in the sensor cabling. Because of the resistance in the metal sheathed cable (See Figure 15) there exists a small voltage across that resistance that is caused by the carrier signal at 1 MHz. If, for example, two sensors are electrically connected, one will act as a very small voltage generator connected to the other. This generated voltage is represented by Vg in Figure 15 and say it is precisely 10 Hz lower or higher than the 1 MHz oscillator frequency of the first sensor. A 10 Hz beat frequency will thus be introduced and will be detected at the system's output.

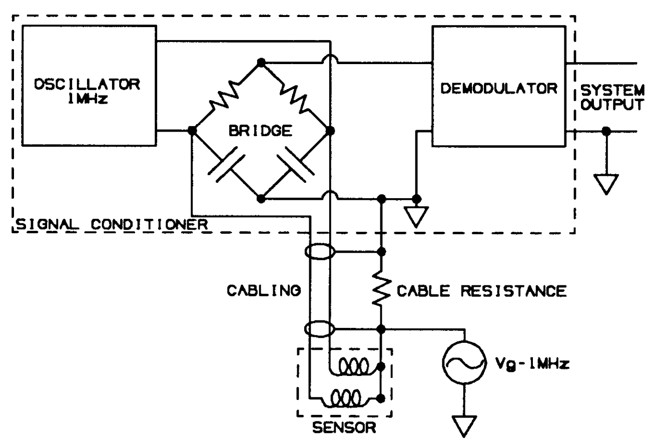


Figure 15

The second basic method for introduction of cross talk is electromagnetic coupling between sensors. The sensor case is not a 100% perfect attenuator and thus a small 1 MHz electromagnetic field will permeate the case and be superimposed with a corresponding field of a sensor in close proximity. This intermixture of fields of almost identical frequency will again cause the frequency difference (beat frequency) to be detectable at the output of both systems.

The third source of beat frequency interference is caused through the interconnection of the leads from a common input power supply. Due to internal voltage regulation of each system, this type of interference is seldom encountered even with very long power supply cables.

Any and all of the above interferences can be eliminated by synchronization of the oscillators in question as herein described.

Any one of the electronics units can be selected as the "master" oscillator since all standard units are factory connected to be such. Thus no modification is required for use as masters (syncors). Having chosen the master unit, all remaining units can be modified to function as "slave" oscillators (syncees). As many as twenty "slave" units can be synchronized with one "master" unit. The "master" unit may be placed anywhere in the synchronized chain as all units are connected in parallel. This "master-to-slave" modification can be factory installed when ordering, or the modification can be performed by the user utilizing the special modification kit, part number 850897-001. The instructions that follow apply to the user modification.

2.0 Instructions for Customer Modification

2.1 Turn power supply off and disconnect power supply from all electronic units to be modified.

2.2. Remove the cover from the Signal Conditioning Electronics by removing the eight cover screws.

2.3 Remove the six screws which secure the exposed (upper) circuit boards and keep these screws segregated from the eight cover screws of section 2.2.

2.4 Hinge the exposed two circuit boards up and away from the connectors to allow access to the lower circuit board.

2.5 Locate the Jumper Wire (JW1) on the lower circuit board (see Figure 16). Note that one end of this jumper wire is soldered to a circuit board pad whereas the other end is plugged into a mechanical receptacle labeled "M", denoting "master". The black heat sink may be carefully pulled off the component near the jumper wire to make the jumper wire more accessible if desired.

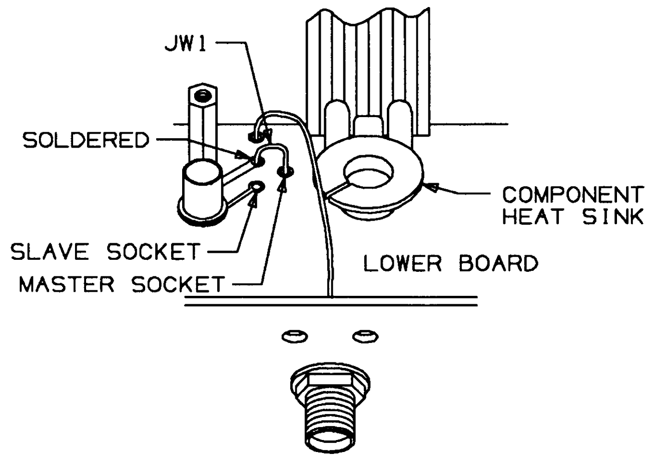


Figure 16

2.6 Using long nose pliers, grip the jumper wire near the mechanical receptacle and pull it from that socket. Rotate the jumper wire clockwise and insert it firmly into the mechanical socket labeled "S", for "slave".

2.7 If the heat sink was removed, in step 2.5, carefully install it on the component from which it was removed pushing the heat sink until it contacts the component flange.

2.8 Re-position the top circuit boards and install the four Fillister Head screws in the corners and the two Binder Head screws between the two upper circuit boards. Tighten these six screws to hold the circuit boards firmly in place.

2.9 Replace the cover after making certain that its serial number is identical to that on the smallest upper circuit card. Install the eight cover screws.

2.10 Identify the "master" and "slave" units with the stickers provided as part of the synchronization kit. The sticker can be applied below the small "Sync Input/Output" connector that is centrally located (see Figure 16.)

2.11 Connect the "tees" and "interconnecting cables" provided with the kit (part no. 850897-001)

This completes the synchronization conversion. The process can be reversed if desired by returning the jumper wire to the "master" position. The failure of a "slave" unit will not alter the operation of any other units; however, the failure of the oscillator of the "master" unit will affect all units synchronized with it. In the latter event, any of the "slave" units may be reconverted to a "master" unit to restore operation of all remaining units (exclusive of the previous "master" unit).

APPLICATION NOTE #206

Radiation Sensitivity Kaman Extreme Environment Pressure Transducers

Kaman extreme environment eddy current transducers use two coils to reduce the parasitic effects of radiation, temperature, and other undesirable environments. Tests have shown that each coil, when exposed to an integrated neutron flux of $8x10^{19}$ nvt, experiences a change of inductance of approximately 0.5% and a change of resistance of approximately 7%. These changes are sufficient to cause appreciable error in a measurement system if a single coil is used; however, since both coils of a dual coil design experience nominally the same integrated dosages, the effects of radiation are canceled by the detection bridge to the first order in a manner patented by Kaman (see ref. {1}). For more detailed transducer information see references {2} and {3}.

Since the environment and parameters of both coils cannot be made perfectly identical in geometry and in time, a "radiation error signal" is experienced during a radiation pulse or other transient condition. Figure 17 illustrates the results of such a test on a Kaman low temperature pressure transducer fabricated from high thermal conductivity alloys. The parasitic radiation signal of 2.6% of full range occurred when the gamma exposure rate was $10^{15}\,R/hr$ and the neutron flux was $10^{15}\,n/cm^2-$sec. The total integrated neutron fluence and gamma exposures were $10^{16}\,n/cm^2(nvt)$ and $10^{6}\,R$ respectively. (See reference {4}).

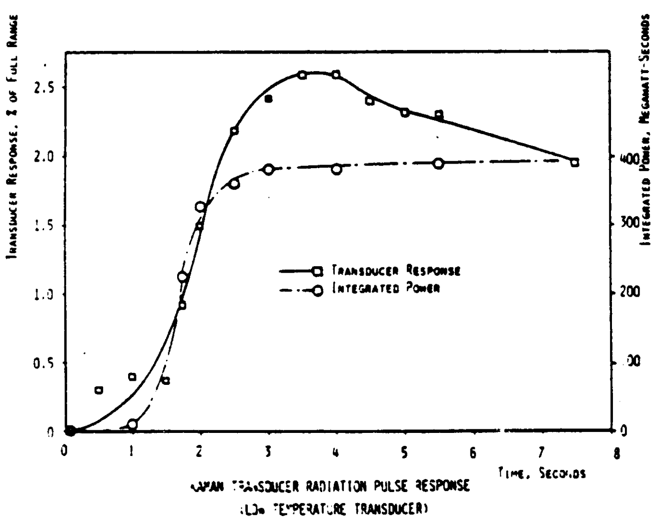


Figure 17

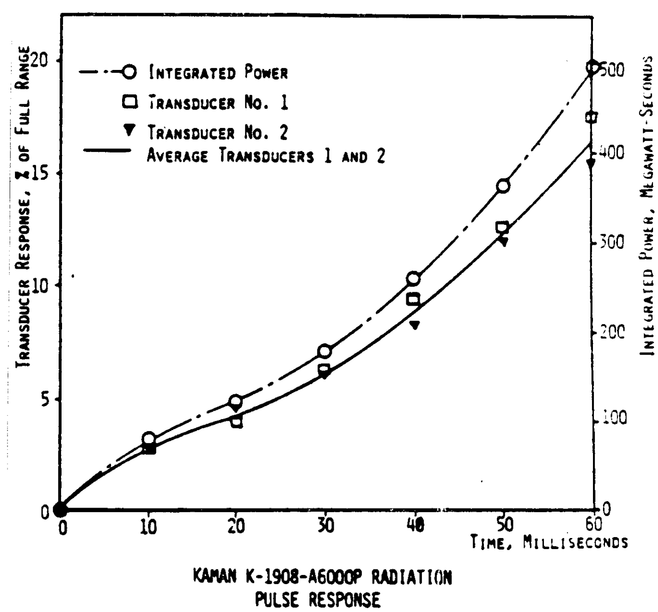


Figure 18

Figure 18 illustrates the results of a test of two Kaman K-1908-A6000P pressure transducers when exposed to a reactor pulse in the TREAT reactor. These transducers are fabricated of a high strength alloy with a low thermal conductivity. It is found that the "radiation error signal" is approximately 0.034% F.R. per megawatt-second of integrated reactor power for these first 60 milliseconds of the radiation pulse. The associated integrated neutron fluence and gamma exposure conversions are

$5x10^{12}\, neutrons/cm^2$ per megawatt-second and $6x10^3 R$ per megawatt-second, {5}. For the time represented in figure 2, the radiation exposure rates are approximately $4x10^{16}\, neutrons/cm^2 -$ sec and $1.8x10^{11} R/hour$.

Upon termination of the radiation pulse, the transducer's response returned to null (zero output signal) as the trend indicates in Figure 17. The "decay" to zero is due to cooling of the transducers which where heated by gamma radiation during the pulse at a rate of approximately 0.08°C per megawatt-second of reactor energy.

REFERENCES

{1} Transducer Patent No. 3,238,479, Peter K. Church, United States Patent Office, Patented March 1, 1966.

{2} Schneider, John C., "Remote Measuring Instruments for Extreme Environments", Transactions of the American Nuclear Society 1972 Annual Meeting, Volume 15, Number 1, June 1972, pages 365-366.

{3} Schneider, John C., "Measuring Instruments for Extreme Environments", Instrumentation in the Aerospace Industry, Vol. 18, 1972, Proceedings of the 18th International ISA Aerospace Instrumentation Symposium, May 15-17, 1972, Instrument Society of America, Pittsburgh, Pennsylvania, pages 289-294.

This publication is listed in Zentralstelle fur Atomkernenergie-Dokumentation, Information zur Kernforschung und Kertechnik, Referatezeitschrift Mil Register, 1972, Nr. 8, page E42, E423056, AED-Conf.-72-156-001.

{4} Boland, James F., Nuclear Reactor Instrumentation (In Core), 1970. Gordon & Breach Science publishers, New York, London, Paris; pp. 64-66. Other eddy current instruments are also described in this reference on p. 81, 89, 108.

{5} Data furnished courtesy of Argonne National Laboratory.

APPLICATION NOTE #208

Noise and Resolution
KP-1911 Series Pressure Measuring Systems

Abstract

This application note discusses some commonly used methods for specifying noise levels. Several examples of noise calculations are shown. The relationships between noise, resolution and threshold are discussed. Throughout the application note, methods for improving signal-to-noise ration, resolution, and threshold are given.

Noise

Noise might be defined as any unwanted signal. The noise of primary interest in the KP-1911 series systems is random noise which has random frequency and amplitude. The noise which is of secondary interest is the continuous wave (CW) noise at fixed frequencies. There are two common types of CW noise. The first type is that caused by ground loops in the instrumentation system. A signal related to the AC power line frequency would be typical of this type of noise. Since a thorough discussion of ground loops is beyond the scope of this application note, this type of noise will not be discussed any further.

The second type of CW noise is carrier feedthrough. This is the 1 MHz feedthrough from the oscillator and the 2 MHz feedthrough from the synchronous demodulator. Because of the output filtering in the KP-1910 electronics, this noise is small in comparison to the random noise.

There are various methods of specifying random noise outputs. Relationships between these methods of specification will be described. Two points are basic to understanding noise specifications: First, noise is a <u>power</u> function (as opposed to a voltage or current function); secondly, noise specifications must include a relationship to power bandwidth (expressed or implied).

Since noise outputs are random in frequency, doubling the measurement bandwidth will not double the measured voltage, but instead will double the power. Therefore, random noise is properly specified as a noise power per unit bandwidth, e.g., $\mu V / \sqrt{Hz}$.

Broadband Noise Specifications

One common method of specifying noise is to give the maximum rms output noise level from an instrument throughout an essentially unlimited bandwidth. This is the method used for the KP-1911 systems.

White noise is defined as a continuous random noise distributed uniformly across the frequency spectrum; in other words, its rms amplitude per unit bandwidth is constant. Therefore, the total rms amplitude of the noise will increase as the measurement bandwidth increases. This is expressed mathematically as:

$$\overline{P_n} = \int_{f_1}^{f_2} p_n \, df = p_n(f_2 - f_1)$$

$$\overline{P_n} = p_n BW \qquad (1)$$

where: $\overline{p_n}$ = total rms noise power

p_n = rms noise power per unit bandwidth

BW= measurement bandwidth $(f_2 - f_1)$

Applied to noise voltage this expression becomes:

$$\overline{e_n} = e_n \sqrt{BW} \qquad (2)$$

where: $\overline{e_n}$ = total rms noise voltage

e_n = rms noise voltage per root unit bandwidth

It would seem from the above discussion, then, that a measurement bandwidth must accompany a noise specification or else the noise level would be essentially unlimited. This is true, but often there is an implied bandwidth. This is the case with the KP-1911. As stated in its specifications, it has a zero to 10 KHz (standard) bandwidth; therefore, the noise measurement bandwidth has been determined by the output characteristics of the electronics and is not dependent upon the external measurement bandwidth (presuming it is greater than 10 KHz).

It might also be pointed out that for systems such as the KP-1911 which have carrier signals, the carrier feedthrough may increase the output noise level considerably above the databand (in this case 0-10 KHz) noise level. This is not true for the KP-1911 since the carrier feedthrough is small in comparison to the databand noise. For instruments which have appreciable carrier feedthrough it is best to specify both data band noise and carrier feedthrough, or data band noise and total (broadband) noise. This is important because the user's readout equipment may or may not respond to the carrier feedthrough.
For example, a strip chart recorder will not respond to a 1 MHz signal, whereas a wide band oscilloscope will.

Application of Noise Specifications

We have seen in equations 1 and 2 the basic meanings of noise power and noise voltage. Since the noise voltage is the more commonly specified, we will see how it can be used for estimating the total noise voltage in a specific bandwidth.

Example One:

What would the total output noise voltage be if the KP-1911 were ordered with the zero to 50 KHz bandwidth option?

First we calculate e_n for the standard 10 KHz bandwidth by rewriting equation 2:

$$e_n = \overline{e_n} / \sqrt{BW} \qquad (3)$$

$$= 0.5mVrms / \sqrt{10KHz}$$

$$= 5\mu Vrms / \sqrt{Hz} \qquad (4)$$

This important result is then used for determining the total output noise voltage in a specific bandwidth as we will see by continuing our example.

Using the above result in equation 2 with a 50 KHz measurement bandwidth:

$$\overline{e_n} = e_n\sqrt{BW}$$

$$= \frac{5\mu Vrms\sqrt{50KHz}}{\sqrt{Hz}}$$

$$= 1.12mVrms$$

Thus, as expected, the noise increased as the bandwidth increased.

Example 2:

Suppose that the output data from a KP-1911 system is to be analyzed using a spectrum analyzer with an IF filter bandwidth of 100 Hz. (The IF filter sweeps through a given frequency range, e.g. 20 KHz, and measures all signals appearing in its 100 Hz bandwidth as it sweeps.) What would be the noise floor for this measurement? This is calculated using equation 2, the result in equation 4, and a 100 Hz measurement bandwidth:

$$\overline{e_n} = e_n\sqrt{BW}$$
$$= \frac{5\mu Vrms\sqrt{100Hz}}{\sqrt{Hz}}$$
$$= 50\mu Vrms$$

Thus we see that the noise level can be significantly reduced by having a very limited bandwidth.

A technique similar to this is in common usage in acoustical measurements. That technique consists of using filters with bandwidths of one octave or one-third octave. By using a number of these filters a wide data band can be covered but with a significant reduction in noise level in each octave or one-third octave increment of the databand.. An important point to remember when using these filters is that the noise level when each octave (or one-third octave) is not the same, as shown in the following example.

Example Three:

If octave band filters were used with a KP-1911 system, what would the noise levels be in the 100 Hz to 200 Hz octave and the 1 KHz to 2 KHz octave?

Proceeding as in example two for a 100 to 200 Hz bandwidth:

$$\begin{aligned}\overline{e_n} &= e_n\sqrt{BW}\\ &= \frac{5\mu Vrms\sqrt{(200-100)Hz}}{\sqrt{Hz}}\\ &= 50\mu Vrms\end{aligned}$$

For a 1K to 2KHz bandwidth:

$$\begin{aligned}\overline{e_n} &= \frac{5\mu Vrms\sqrt{(2K-1K)Hz}}{\sqrt{Hz}}\\ &= 158\mu Vrms\end{aligned}$$

Thus, it is evident that the noise level is not the same in each octave band.

Note that the above discussion and examples presume that e_n is not a function of frequency, or in other words, that the output noise is white noise. This point is noted because in many types of instruments there occurs a type of noise which increases with decreasing frequency. This noise, usually referred to as 1/f noise, normally begins to become predominant over the white noise at a frequency around 200 to 500 Hz. The output noise of the KP-1911 is predominately white noise down to a frequency of at least 10 Hz. therefore, calculations similar to those shown in the examples will be valid down to a frequency of at least 10 Hz.

Noise Specification in Terms of Decibels

The term decibel implies some type of ratio measurement, usually relative to a fixed reference level. In instrumentation systems this reference is frequently the system's full scale output voltage. On the other hand, a decibel specification can legitimately be with respect to any stated reference. There are also several standard decibel scales in common usage, for example, dBm, dBV, dBSPL which imply rms reference levels of 1 mW into 600 ohms, 1 volt, and $20\mu N / m^2$ respectively.

We will now examine how a signal-to-noise specification in decibels could be calculated for the KP-1911 system. The standard full scale output voltage is 1 VDC while the broadband noise level is 0.5 mVrms max. At first it might seem inconsistent to compare DC and rms values. Recall, however, that noise is a power density function, thus we can write:

$$S / N = \frac{(E)^2 / R_L}{(\bar{e}_n)^2 / R_L} \frac{(watts)}{(watts)} \qquad (5)$$

$$= 20\log(E / \bar{e}_n)(dB) \qquad (6)$$

where: S/N=signal-to-noise ratio

E=full scale DC output voltage

$\bar{e}_n$ = total rms output noise voltage

R_L = output load resistance

Thus the signal-to-noise ration (broadband) for the KP-1911 can be calculated:

$$\begin{aligned} S / N &= 20\log(1V / .5mV) \\ &= 66dB \end{aligned} \qquad (7)$$

Note that this result is a broadband specification. Sometimes it is desirable to know the relative noise level per unit bandwidth (with respect to the full scale output voltage) for ease of calculating the signal-to-noise ratio for a given bandwidth. Substituting equation 2 into equation 5, the signal-to-noise ratio as a function of bandwidth can be expressed as:

$$S/N = \frac{E^2/R_L}{\left(e_n\sqrt{BW}\right)^2/R_L} = \frac{E^2}{e_n^{\,2}}\frac{1}{BW}$$
$$= 20\log\frac{E}{e_n} - 10\log BW$$

(8)

Thus, once the value of the term 20 log E/e_n has been found, one can determine the signal-to-noise ratio for various bandwidths. To illustrate this fact we will repeat examples one through three, this time expressing the answers in terms of signal-to-noise ratios.

Example Four:

What would the S/N ratio be if the KP-1911 were ordered with the 50 KHz bandwidth option?

Using the value for e_n found in equation 4 and a full scale voltage E^n of one volt, equation 8 yields:

$$S/N = 20\log\frac{E}{e_n} - 10\log BW$$
$$= 20\log\frac{1V}{5\mu V} - 10\log 50K$$
$$= 106dB - 57dB$$
$$= 59dB$$

Example Five:

What is the S/N ratio if spectrum analysis is performed with a 100 HZ IF bandwidth?

Using a portion of the above result and equation 8:

$$S/N=106dB-10\log 100$$

$$=86 \text{ dB}$$

Example Six:

What are the S/N ratios of 100 to 200 Hz and 1K to 2KHz octave band filters are used?

For the 100 to 200 Hz octave filter the S/N ratio is:

$$S/N=106dB-10\log(200-100)$$

$$=86 \text{ dB}$$

For the 1K to 2KHz octave filter:

$$S/N=106\text{ dB}-10\log(2K-1K)$$

$$=76 \text{ dB}$$

It can be noted from the above examples that for each decade decrease in bandwidth there is a 10 dB increase in signal-to-noise ratio.

RESOLUTION

According to the definitions published by the Instrument Society of America, the term resolution does not properly apply to devices such as the KP-1911 but rather to potentiometeric transducers which have discrete, measurable output steps. In this sense, an instrument such as the KP-1911 has infinite resolution, however, this claim is not really very useful to the user. On the other hand, neither is the ISA's suggested substitute for resolution -- the term "threshold". Threshold is defined as "the smallest change in the Measurand that will result in a measurable change in Transducer Output." The reason for this obscurity is , of course, that it is extremely difficult to determine what is a minimum measurable change in output. This problem is discussed, but not necessarily resolved, in the next sections.

Resolution with DC Voltmeters

In the case of measurements with digital voltmeters, the term resolution is truly applicable because the output does change in discrete steps. Therefore, the resolution of the whole system cannot be better than the resolution of the DVM. However, for DVM's which have resolution greater than 1 mV, the approximate noise floor of the KP-1911, there begins to be some question. The resolution then becomes dependent upon the DVM's bandwidth and its general noise immunity. In practice, most 4-1/2 digit, DVM's have characteristics such that they can resolve 0.1 mV with a KP-1911 system to obtain an 80 dB resolution.

Note that a KP-1911 with a higher output voltage option (e.g., 5VFSO) has approximately the same signal-to-noise ratio and therefore the same resolution in dB as a standard 1VFSO unit. That is, the maximum output noise voltage for a 5VFSO unit is 2.5 mVrms. Two possible advantages of a higher output voltage are:

(1) To improve the ratio of the output voltage to the input noise voltage of a recorder or other instrument;

(2) To obtain an output voltage in engineering units; for example, a 2000 mV output voltage for a 2000 psi system.

Threshold in Dynamic Measurements

A digital voltmeter is a very good device for monitoring a static or a very very slowly changing output; however, when the measurand is changing rapidly, other devices must be used to monitor the dynamic output. Instruments such as oscilloscopes, AC voltmeters, and spectrum analyzers are examples of instruments commonly used to measure dynamic (AC) voltages. An oscilloscope can simultaneously display both the AC and DC components of a voltage, while AC voltmeters and spectrum analyzers respond to only the AC portion of the voltage.

What then is the threshold with the above devices? To answer this question we must define a "measurable change in output". The reader can probably already perceive the problem-one person's "measurable change" may not be the same as another person's. In other words, how does one quantify a "measurable change". Unable to answer this directly, we can state that the "measurable change" is certainly limited by the output noise level. How much "measurable change in output" a person can discern superimposed upon the noise level with an oscilloscope will probably depend on the person who is discerning it. We repeat, however, that the smaller the bandwidth the lower the noise level. Thus, the threshold can definitely be lowered by decreasing the measurement bandwidth in those applications which will allow this.

The previous comment will also apply to measurements made with AC voltmeters, however, there is a new twist to discerning a "measurable change". For example, if there is an output noise level of 1 mVrms and an output signal level of 1 mVrms is added, a true RMS AC voltmeter will not read the sum of the two (i.e., 2 mVrms) but will read the square root of the sum of the squares (i.e., 1.4 mVrms). (This is also approximately correct for average responding voltmeters.) Thus, for low signal levels the magnitude of the signal could be estimated using the formula:

$$e_s = \sqrt{V_0^2 - \bar{e}_n^2}$$

where: e_s = estimated output signal

V_0 = the AC voltmeter reading

e_n = output noise voltage (broadband) measured in the absence of a measurand signal

The threshold with a spectrum analyzer will improve as the IF bandwidth is narrowed and will be limited by the noise level in that bandwidth as discussed previously. It would be reasonable to detect signals 1 to 2 dB above the noise level with a spectrum analyzer. The correction factor for an accurate, low-level measurement will depend upon the spectrum analyzer used.

SUMMARY

A noise specification is important because the noise level is the factor which limits the resolution (or threshold) of the KP-1911 system. Specifying the threshold is difficult, if not impossible, and is quite dependent upon the instrumentation following the KP-1911 system. Therefore, the discussion in this application note have attempted to acquaint the reader with the factors which modify noise levels and thresholds. The primary modifier of the noise level is bandwidth and the primary modifiers of threshold are the readout equipment and the desired accuracy.

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